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Human-Powered Concrete Mixer

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ENTITLED

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DESIGN AND IMPLEMENTATION OF A HUMAN-POWERED CONCRETE MIXER

By

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SENIOR DESIGN PROJECT REPORT

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Abstract

There are currently many non-profit organizations and social enterprises working to alleviate the hardships of living in a developing economy, such as lack of proper homes, schooling, and bathrooms. The solutions to these problems rely on concrete, and are currently limited by the mixing time for these batches of concrete in rural and remote areas. Mixing with shovels is inefficient and imprecise, and the possible solution of a portable gas-powered concrete mixer is too expensive and too immobile for remote areas. The Human-Powered Concrete Mixer (HPCM) provides an alternative to these methods that is more efficient and more precise than hand mixing with shovels, yet cheaper and more mobile than a portable gas-powered concrete mixer. Our team was able to successfully design a mixer that, in comparison to mixing with shovels, reduced mixing time from 15 minutes to 5 minutes, reduced the necessary number of laborers from 6 to 2, and produced structurally sound concrete. The modular design of the mixer allows the HPCM to be easily moved to remote construction areas, and the cost of the mixer makes it more economically viable for non-profit organizations and social enterprises than a gas-powered alternative. In sum, the HPCM provides a low cost, efficient, mobile, and reproducible alternative that enables non-profit organizations and social enterprises to more effectively help more people.

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Chapter 1: Introduction

1.1 Problem Statement

Amigos for Christ, a social enterprise based in Chinandega, Nicaragua, works to improve the lives of community members in a variety of ways, most notably through partnering with communities to install clean water and sanitation systems, improve schools, and construct clean-air kitchens. All three of these project areas require the production of concrete, whether it is used in the base of water towers, the foundation of school buildings, or the construction of modern bathrooms. A limiting factor in this building process for Amigos for Christ is their ability to mix batches of concrete efficiently. Until recently, Amigos for Christ mixed all concrete by hand with shovels. A simplified schematic for this process is shown in Figure 1.1.1, which shows the problems that Amigos for Christ is trying to solve with their respective solutions, and how each of these solutions relies on mixing concrete.

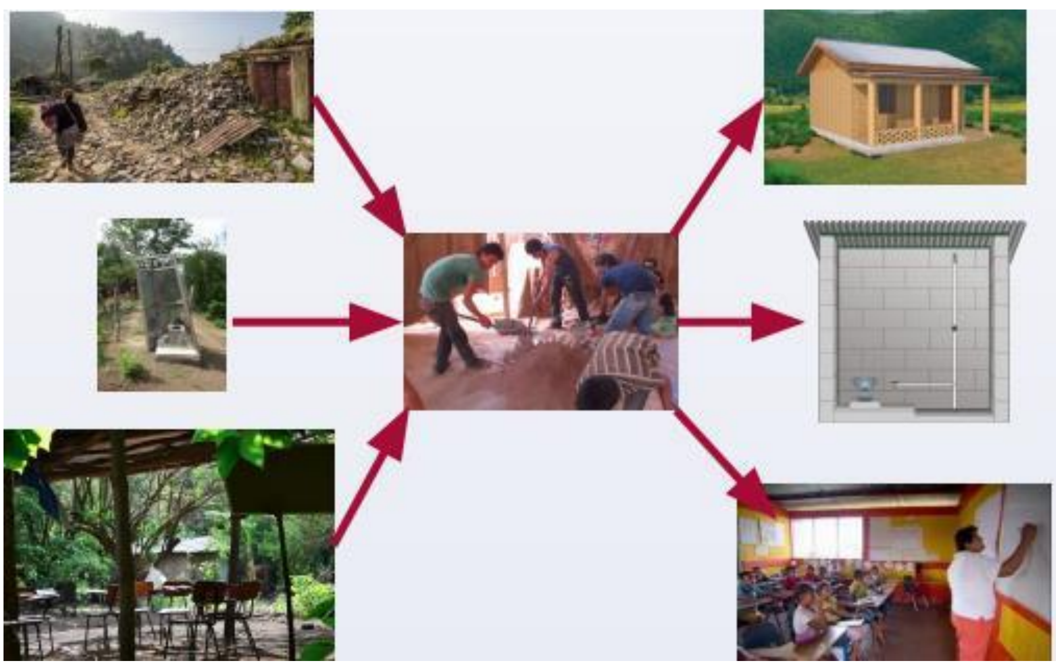


Figure 1.1.1. Simplified Construction Schematic for Amigos for Christ

In the past 3 years, Amigos for Christ has implemented a gas-powered mixer at its largest project site, construction of a K-12 school that will include 8-10 buildings. The introduction of this gas-powered mixer drastically increased the speed of this project, and Amigos for Christ is looking for a similar effect with their other projects. However, the size, weight and cost of a gas-powered mixer render it an impractical option at their more remote project locations. As a result, Amigos for Christ requires a cheap, mobile alternative to the gas-powered mixer. This mixer must be more efficient and easier to use than the current method of mixing by hand with shovels.

1.2 Background and Related Work

Though the Human-Powered Concrete Mixer (HPCM) will be used in Nicaragua upon completion, our team began the school year working on a project for Conscious Impact, a social enterprise based in Takure, Nepal. A former Conscious Impact representative contact the Santa Clara School of Engineering, asking for help speeding up the reconstruction process in Takure following the Gorkha Earthquake of 2015. The representative brought the project to the attention of the Mechanical Engineering department, and was a primary point of contact between the team and Conscious Impact. It was possible to transfer the project area from Takure to Chinandega because they were facing a similar issue, as both Amigos for Christ and Conscious Impact lacked efficient ways to mix concrete for their projects. For both groups, they felt that the limiting factor in their ability to produce buildings was their mixing time.

The existing method for both groups involved mixing raw materials -- cement, water, rocks, and sand -- with shovels on the ground to produce concrete, shown in Figure 1.2.1.

Figure 1.2.1. Current Method- Mixing with Shovels

This process requires 4-5 people to mix the dry raw materials while another individual adds water until a proper consistency is achieved. The mixing process usually takes around 15 minutes, and requires that the mix be loaded into buckets to clear the area for another batch to be mixed. Each batch produces around 0.08 cubic meters of material. Amigos for Christ is capable of producing around 30 of these batches per day. For their largest project, the construction of a K-12 school in La Chuscada, Chinandega, Amigos for Christ purchased a portable gas-powered concrete mixer, similar to that pictured in Figure 1.2.2.

Figure 1.2.2. Gas-Powered Concrete Mixer

This gas-powered mixer has drastically increased the amount of concrete that Amigos for Christ has been able to produce batches of concrete in 5 minutes rather than 15. In addition to being three times as fast, the gas-powered mixer only requires 3 operators, thereby freeing up 3 people to work on other parts of the concrete process, such as carrying buckets of raw material to the mixer or carrying buckets of finished concrete from the mixer to the location the concrete will be used. This gas-powered mixer is feasible for the La Chuscada construction site because it can stay largely stationary, and is close enough to the large city of Chinandega that gasoline is readily available.

1.3 Review of Literature

One of the defining features of a concrete mixer is its power source. Most commercially available concrete mixers run on either gas or electricity. However, traditional human power concrete mixing methods are inefficient. Examining other ways to use human power led to a more efficient mixer that did not require external power and was highly mobile.

Human-powered machines are common in most societies. Common examples include bicycles, human-powered forklifts, and paddleboats. (Wilson). One of the most impressive human powered vehicles is the Atlas Human-Powered helicopter, built for a competition hosted by the Sikorsky company. The helicopter was able to reach a height of 3 meters and could fly for 60 seconds (Robertson). The power transmission system of this machine was more complicated than would be necessary in the concrete mixer. Though it does not directly apply to a human-powered mixer, the success of this helicopter indicates the potential for human-powered machines and the feasibility of a human-powered concrete mixer. A particular characteristic that all these human-powered machines have in common, and that was useful for our design, is an emphasis on weight reduction (Ari et. al).

Our mixer was initially designed to mix the earth to form stabilized compressed earth blocks (SCEB). As a result, the properties and uses of these blocks were researched. Though the final product was changed from compressed earth to concrete, the research on mix consistency was still relevant. One article showed that the water content does not have to be very precise. (Zhemchuzhnikov). This was concluded after studying the effects of water content and compaction rate on the end strength of SCEBs. This indicates that as long as the water content is high enough to allow for curing of the cement, the compaction process will produce blocks with the appropriate moisture content for curing and drying. By decreasing the time necessary to evaluate water content, the mixer operation time is significantly reduced. This research was still relevant to the HPCM while mixing concrete, as the curing process for the cement is largely the same despite different aggregate.

In addition, research was conducted into current rebuilding methods being implemented in Nepal. A team of engineers from Tribhuvan University conducted field research on remaining buildings' resistance to seismic activity. It was found that most of the buildings made of reinforced concrete did not experience structural damage (Dizhur). The buildings that were damaged had other factors that amplified the earthquake's effects. The study states that, “The localized failure of reinforced concrete buildings, in Kathmandu valley and out, may be attributed to amplification of waves in thick soft soil deposits, poor quality of construction, inadequate column sizes and lack of ductile detailing” (Shrestha) This is useful to know, because

SCEBs share many material properties with reinforced concrete. The results of the study support the use of SCEBs in earthquake prone areas.

The effect of mixing concrete on mixer blades was also researched in order to gain a better understanding of the longevity of the machine. It was found that different mixing styles caused different types of wear, with the most considerable wear coming in concrete mixers that were using larger aggregate (Valigi). This is important to know because the mix being created in Chinandega has a relatively large aggregate. This was important in the design process, as we had to select durable materials for use as mixer blades.

In addition to research into similar projects and concrete, it was also necessary to conduct research into the socio economic factors which might impact the ability of our designed to be used. Of particular importance was the fact that Nicaragua is the 2nd poorest country in the Western Hemisphere (International Monetary Fund). This knowledge is relevant to design decisions, as it emphasizes the fact the design must be low cost in order to be of value in Nicaragua.

1.4 Project Objectives

The goal of this project was to provide an alternative concrete mixing method for Amigos for Christ in their rural building locations. The four main project objectives for the Human-Powered Concrete Mixer, as summarized in table 1.4.1 below. Each of these objectives are addressed in more detail following the table.

Table 1.4.1. HPCM Project Objectives

Objective	Solution Had to Be:	Steps Taken to Achieve
Low Cost	Low cost due to the levels of poverty in Nicaragua and tight budget of Amigos for Christ.	-use of bulk materials -use of refurbished/used parts -use of human power
Efficient	Efficient to maximize the work done by human power output, and to accelerate the building process.	-maximization of mechanical advantage -selection of optimum mixing angle
Mobile	Mobile to allow Amigos for Christ to move the mixer between remote project locations.	-minimization of loose parts -design into separable subsystems for transportation
Reproducible	Reproducible so that it could be built not just in the Machine Shop at SCU but in rural Nicaragua as well.	-use of parts available in rural Nicaragua -minimization of high-precision machining processes

Low Cost

One the most important project objectives was to design a low-cost product. Specifically, the mixer was designed to compete with gas-powered mixers, the cheapest of which cost around $500. As was mentioned in Section 1.3, Nicaragua is the 2nd poorest country in the Western hemisphere. The areas in which Amigos for Christ operates, and especially those in which a human-powered concrete mixer would be used, has some of the poorest and most remote areas in the country. As a result, the cost of the mixer is important to the success of the design. In order to make the mixer low cost, it was essential to carefully select materials. As will be discussed in the subsystem chapters, the geometry of the frame and the choice of materials was affected by the low-cost objective. When possible, refurbished parts were selected -- specifically the drum and bike wheels. Finally, the low-cost objective was the main driving factor in implementation of a human-powered system, as this is a renewable energy source that will not cause the user recurring costs, such as purchasing of gasoline.

Efficient

In order to make sure that the HPCM is viable for Amigos for Christ, our design had to be significantly more efficient than the existing method of mixing with shovels. As is discussed in the PDS (see Appendix 1), it was necessary to increase the total concrete output of Amigos for Christ by a factor of 2.5-3 in order to make the system viable. This factor was derived from the increase in efficiency gained by implementing a gas-powered concrete mixer, as the HPCM was designed to match the efficiency of gas-powered mixers. The main aspect of efficiency that had to be considered was the conversion of human power to mixing power. In order to accomplish this, our design achieved a sufficient mechanical advantage to mix at the most efficient mixing angle, as determined through testing of the prototype.

Mobile

Through initial design formulation, our product was not intended to be mobile, in accordance with specifications from Conscious Impact. However, for Amigos for Christ, it became apparent that a mobile system was required due to the need to transport a mixer to several remote project sites. As a result, it became a project objective to make the system mobile, in that it would be easy to move between different remote building locations. This was accomplished by altering the design so that the three main subsystems could be taken apart for transportation, so that the mixer took up less room during transportation. Each subsystem was also evaluated separately to ensure that two people could carry each subsystem easily.

Reproducible

The system also must be easily reproduced so that multiple versions could be made in Nicaragua if desired by Amigos for Christ. It was also important in our design choices, as we had to ensure that the mixer could be easily manufactured in rural Nicaragua, where they do not have the capabilities of the machine shop at Santa Clara University. Consequently, mills and lathes were used as infrequently as possible, due to the lack of similar machining capabilities in Nicaragua. In the end, the mill was used for one step in manufacturing. This process required the mill due to space restrictions around the drill press in the machine shop, rather than functionality that was only available through use of a mill. Amigos for Christ confirmed that they will have access to a drill press and horizontal band saw in the city of Chinandega, making all part modifications feasible in Nicaragua. The details of manufacturing, and how specific manufacturing issues were addressed, is discussed in more detail in Chapter 4 through Chapter 7.

In sum, the goal of this project was to expedite the process of mixing concrete that is currently being used in rural Nicaragua. In order to accomplish this overarching goal, it was determined that our mixer had to be low cost, efficient, mobile, and reproducible. In this way, our mixer will plug into the existing construction methods at Amigos for Christ, helping to accelerate their construction processes, as shown in Figure 1.4.1.

Figure 1.4.1. HPCM Replacing Method of Mixing with Shovels

Chapter 2: System Level Overview

2.1 Customer Needs

The following is an overview of customer needs, as determined from conversations with Amigos for Christ and Conscious Impact. These customer needs were compared to data from a portable concrete mixer (datum 1) and the current manual mixing process available (datum 2) in order to determine the Product Design Specifications (PDS). For the complete PDS, refer to Appendix I, Table 1. The main design considerations addressed in the PDS, in relation to customer need, are summarized briefly below:

- *Safety* - The machine must not pose a safety hazard to those using it, with the added challenge that the users will most likely have never worked with a concrete mixer of any type.
- *Adjustability* - Different people may need to use the machine, so the the machine was designed to be usable by persons of variable height and strength. This was largely relevant to the human interface to the power transmission.
- *Human Interface* - The human interface had to be intuitive, which pushed the design towards utilization of a human interface that would not require extensive training.
- *Stability* - The machine had to be designed so that it was stable while standing at rest, to avoid tipping over. It also had to be designed to be dynamically stable, which was accomplished by minimizing vibrations during mixing.
- *Durability* - The user required a durable machine that does not need to be replaced or frequently repaired. This was especially relevant when considering components for subsystems so that the system will have maximum possible life.
- *Maintenance/Repair* - The machine must not require frequent maintenance or repair, due to the remote location of the Amigos for Christ projects, which meant materials and technically skilled workers are not readily available.
- *Transportability* - Though not originally a design concern for Conscious Impact, Amigos for Christ indicated that the mobility of the human-powered concrete mixer was paramount due to its use in multiple different locations. The mixer was therefore

designed to be broken down into subsystems and be transported in a truck bed, the dimensions of which were sent by Amigos for Christ.

- *Testing* - The design and final material product were rigorously tested to ensure consistent functionality over multiple uses.

2.2 System Development and Sketches

The Human-Powered Concrete Mixer will be used by the people of Chinandega who are building in remote regions of Nicaragua. The mixer will decrease the time it takes to combine the raw materials-- rocks, sand, water, and cement -- into concrete. The concrete mixer will be provided to the community by the social enterprise, Amigos for Christ. The human-powered concrete mixer will minimize the labor required to mix concrete, thereby freeing up labor for other aspects of construction.

The first iteration of the design for the mixer was comprised of four subsystems. A human interface consisting of a standard bicycle as the power generation unit, a power transmission system consisting of a chain drive, a frame comprised of aluminum and steel conduit, and a mixing drum to hold the material. One person was intended to pedal the bike to turn the drum. Another person was needed to add the cement and earth into the mouth of the mixer and then subsequently add water as needed to reach the desired consistently. Therefore, instead of six people, only two were needed and mixing could be completed in one-third the time of the existing method. Figures 2.2.1 and 2.2.2 below illustrate the initial design.

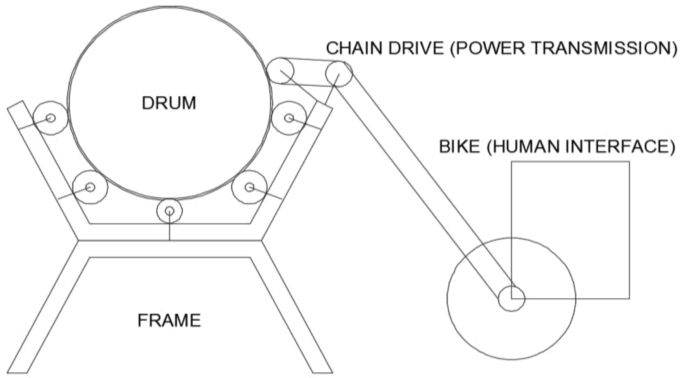


Figure 2.2.1. First Design System Sketch, Front View

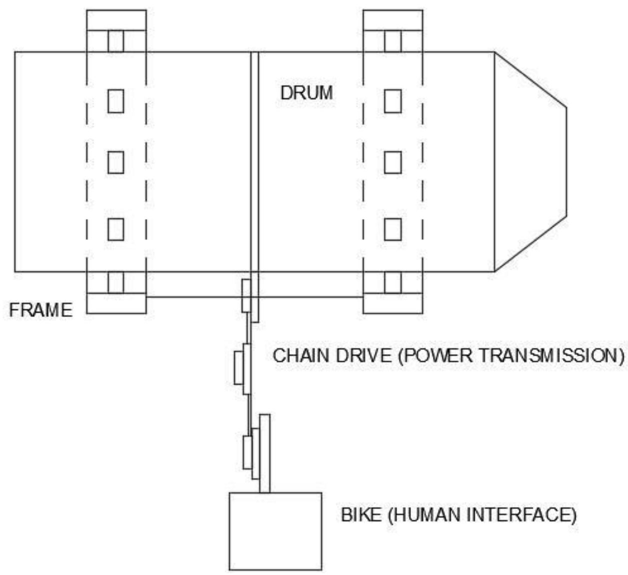


Figure 2.2.2. First Design System Sketch, Top View

Of particular importance in Figure 2.2.1. and Figure 2.2.2. are the interfaces between subsystems, such as that between the frame and the drum, or the power transmission and the drum. Also of note is the conical section in the top view. This was a proposed design change to the drum that allowed for mixing and adding water while helping to ensure that materials are not falling out of the drum while mixing.

One of the main issues that became apparent with this design was that there was not an easy way to mix the material at an angle. This is an important design feature because mixing at an angle allows the user to add water more easily while ensuring that material does not fall out of the drum. In order to combat this, a series of design changes were made. The most important of these was the change in orientation, from the drum being flat during mixing to being at an angle. This required that the system use a series of bevel gears in order to attain the necessary change in angle from the bike wheel power to the drum. The second iteration of the design is shown below in Figure 2.2.3:

Figure 2.2.3. Initial CAD model of Second Design Iteration

After our second iteration of the design, the main issue that was encountered was the cost of the machine. The second design cost estimation was estimated to be around $1600, which was determined to be well out of the price range of the target customers. Table 2.2.1 (below) summarizes several design changes made in order to reduce cost while maintaining product performance.

Table 2.2.1. Summary of Design Changes from Second Design Iteration to Final Design

Subsystem	Design 2	Design Change	Reason for Change
Frame	Welded Connections	Fittings with Set Screws	Cost, Manufacturability
	Square Tubing	Cylindrical Tubing	Cost, Manufacturability
Power Transmission	Gear Train	Ratcheting Handles with Freewheels	Cost, Manufacturability
	Chain Drive	Friction Drive	Cost, Manufacturability, Safety

These design changes resulted in the final design of the HPCM, the system sketches are shown below in Figure 2.2.4. Though the final design may look substantially different from the original, the subsystems may be classified in the same way, as the power transmission and human interface work together to power the drum, which rotates within the frame. An added benefit of final design is the modular design, which allows the mixer to be broken down into subsystems for easier carrying and mobility.

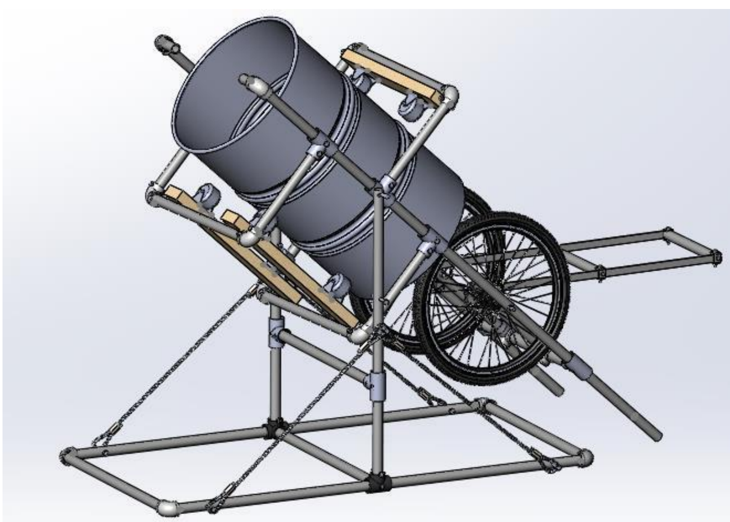


Figure 2.2.4. CAD model of the Finalized HPCM Design

The main subsystems that the user will interact with during use are the upper frame and human interface. During operation, the main ways in which the user will interact with the machine are enumerated below, For a more detailed description, see the User Manual in Appendix 3.

1. **Adding Raw Materials:** The first step in mixing the concrete is adding raw materials into the drum. This is done by lifting 5 gallon buckets of rocks, sand, cement, and water and pouring them into the drum.
2. **Mixing Material:** Once the raw materials have been added to the drum, the drum is rotated in order to mix the material. This is done by using the human interface, which in the final design is a handle that links to the power transmission (for more details, see Chapter 7).
3. **Unloading Material:** Once the concrete has been successfully mixed, the user unloads the mixed concrete by rotating the drum about its pivot axis. To accomplish this, drum stops are first placed between the drum and the upper frame, and then the drum is rotated by the user pushing up on the extended handles of the upper frame at the back of the mixer.
4. **Constructing/Deconstructing the Mixer:** The modular design of the HPCM allows it to be broken down into three subsystems and carried. The mixer is taken apart by removing the drum from the upper frame. The upper and lower frames are then separated by removing the connecting bolt.
5. **Carrying the Subsystems:** The mixer breaks down into subsystems, each weighing less than 100 pounds, making transport sufficiently easy for 2 operators.

2.3 Functional Analysis

The following is an overview of the functional analysis of the machine, which breaks down the active and passive functions of the machine. For the purposes of this analysis, the machine was treated as a “black box” into which inputs were given and outputs were received. As such, this analysis does not assume any features of the machine, but rather focuses solely on what the machine must accomplish. The functions are split into active and passive functions as follows, with sub-functions listed under relevant headings:

Active Functions

- Mixing concrete
    - Mixing dry materials
    - Mixing wet materials
    - Break up clumps that form in mixture
    - Ensure evenly mixed end product
- Allowing a way for raw materials to be gathered for mixing
    - Allowing access to mixed material
    - Allow input of raw material
- Utilize human power
    - Provide mechanical advantage
    - Allow method for intuitive and easy use of power mechanism

Passive Functions

- Support weight
- Have a moment of inertia that allows for maximum efficiency of use of human power
- Frame must allow movement of drum while mixing, and while getting material out of drum
- Allow for user interface/human power

2.3.1 System Subfunctions

For each of these functions, a list of inputs and outputs were considered in order to determine the criteria for the mixer. Three examples are listed below. A full listing of input and output criteria can be found in Appendix G.

Subfunction 1: Mixing dry materials

Inputs: Rocks, sand, water, and cement

Output: Uniformly mixed combination of inputs

Criteria: In order to receive the desired outputs from the given inputs, the machine must provide a mixing process, wherein the three materials are combined and become a mixture.

Subfunction 2: Provide Mechanical Advantage

Input: Human Power, through the ratcheted-handle human interface

Output: Mechanical Power (transmitted to the drum through the bike wheels)

Criteria: The machine must provide an increase in mechanical advantage, greater than could be achieved by a human without the machine. This will make the mixing process easier and more efficient, and therefore shorten the time for rebuilding.

Subfunction 3: Hold all Raw Materials without letting materials fall out

Input: Raw Materials and mixed concrete batches

Output: Same amount of mixed concrete as was expected from the raw materials used

Criteria: The machine must be built in a way that all of the raw materials added end up in the final mixture, thereby ensuring proper ratio of concrete and maximum efficiency of building.

2.4 Benchmarking Results

While there are a variety of existing solutions to the problem, the options found in the research do not fully answer the problem definition. The first option is hand mixing compressed earth and concrete with brooms and shovels. This is the current method in Chinandega and it is shown in Figure 2.4.1.

Figure 2.4.1. Current Mixing Method used in Nicaragua

This is a functional method since they are able to produce the required building mixture. However, this method is very slow and requires 6 or more people for a single batch. The problem statement criteria says that a project goal is to design a product that will be more efficient than this method. In turn, the design should ideally be able to produce the same amount of concrete with a maximum of two people. The next options for mixing concrete are portable electric and gas powered concrete mixers, which are available commercially for small home improvement projects.

Figure 2.4.2. Portable Gas-Powered Concrete Mixer

These mixers, such as the one in Figure 2.4.2, are able to yield a consistent output with a high volume and only need one operator. However, the idea for this project, is that it should be operable in rural Nicaragua, where there is not a reliable power grid. Gas is also costly at around $2.61 per gallon in Nicaragua. Therefore, a commercial concrete mixer would have both a high initial cost of around $616 for lower-end models, in addition to upkeep cost. As a result, this is not a desirable solution for Chinandega, due to the long term costs and sustainability concerns of running a gas engine.

Finally, the human powered concrete mixers designed by the social enterprise, Earth Block International, were investigated. Earth Block International (EBI) has 2 separate prototypes, shown in Figures 2.4.3, and 2.4.4, which they are considering; but, have yet to implement.

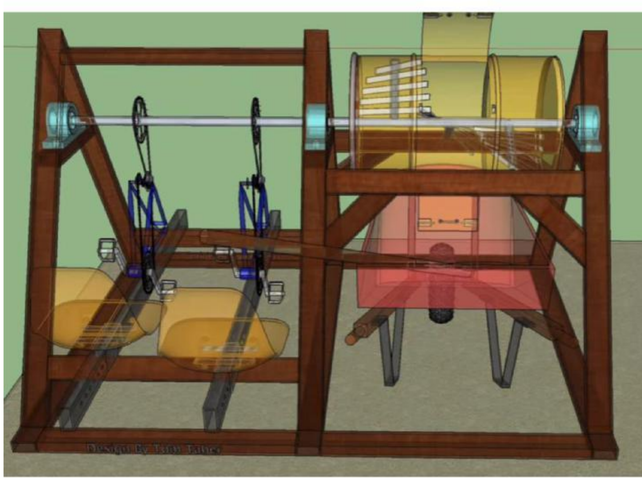


Figure 2.4.3. EBI Design 1

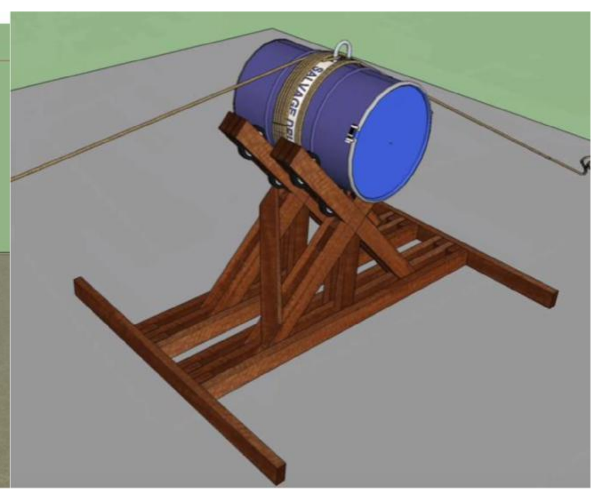


Figure 2.4.3. EBI Design 2

Therefore, there are currently no specifications for the designs. The first design involves 2 users who will power bikes, which then rotate a drum equipped with mixing paddles. This drum is suspended to allow the mix to fall out when a hatch in the drum is opened. The second design is much simpler; however, it is also less functional, as it involves placing the drum on an elevated frame and using a human-pulled rope to rotate it. Another downside of this design is that it lacks an unloading mechanism.

In sum, our mixer was benchmarked against three different potential designs. The first was the existing method of hand-mixing with shovels. The second was the pre-existing solution of a portable gas-powered concrete mixer, which is frequently used for smaller scale construction projects. The third benchmark was other Human-Powered mixer designs, such as those designed by Earth Block International. The results of this comparison are summarized in table 2.4.1 below. Each of these categories (cost, mobility, efficiency, etc.) will be discussed in more depth in Chapters 4-7 which detail each subsystem, as well as in the testing and results chapter.

Table 2.4.1. Comparison of Existing Solutions to HPCM

	Mixing with Shovels	**Gas-Powered Mixer**	**EBI Mixers**	**HPCM**
Initial Cost	$163 (cost of shovels)	$616	N/A	$544
Recurring Cost	-----	$70/yr	-----	-----
Mobile	✓			✓
Reliable		✓		✓
Efficient		✓	✓	✓
Easy to Use		✓	✓	✓
Easily Fixable	✓		✓	✓

2.5 System Level Issues

The key system level issues are the interfaces between subsystems, such as incorporating the drum and the human interface into the frame, or how to attach the paddles to the drum. Before dealing with these interface issues, it was necessary to determine which subsystems would be used. Below is a summary of the decision making process used for the design of the mixer. More detailed subsystem-level selection matrices can be found in the Appendix. It should be noted that different criteria carried different weight for each subsystem. For example, the weight of the power transmission system was not as important as the weight of the drum.

Table 2.5.1. Initial Selection Matrix Inputs

Subsystem	Most Important Criteria	Moderately important criteria	Least Important Criteria
Overall System	Volume of concrete per batch, time per batch, ease of use, cost, weight	Modular, aesthetics, ease of use, reproducibility	Mobility
Drum	Volume, Weight	Rotational power necessary	Cost
Paddles	Cost, installation	Volume of drum, weight	Aesthetics
Power Transmission	Power provided, Efficiency	Cost, Upkeep	Weight
Human Interface	Power provided, ease of use	Cost, price	Weight
Frame	Strength, adaptability, cost	Size of frame	Weight

As can be seen in Table 2.5.1. above, there are certain criteria that are important to the overall system efficiency; but, not to certain subsystems. Although these criteria are less important for that subsystem, they must also be considered within the framework of the entire system. For example, one of the most important criteria for the overall system is the total weight. However, weight is one of the least important criteria for the power transmission. As such, the framework for considering tradeoffs will always be the overall system specifications and criteria.

2.6 Subsystem Options

The following table lists each subsystem and the three main design options for each that were considered during the design process. For sketches of each of these subsystem options, see *Design Sketches* in Appendix E.

Table 2.6.1. Subsystem Options

Subsystem	Option 1	Option 2	Option 3
Drum	Adapted 55 gallon oil drum, 1 paddle	Adapted 55 gallon drum, multiple paddles	Self- Manufactured Drum, adapted with multiple paddles
Paddles	Single axis paddle with multiple branches	Multiple tubular paddles attached to drum (longitudinally)	Angle Iron attached to inside of the drum
Power Transmission	Chain drive	Belt Drive	Friction Drive
Human Interface	Bike	Hand Crank, Ratcheted Handle	Foot Pedal
Frame	Aluminum	Wood	Steel

Table 2.6.1 serves as a summary of the subsystems that were considered for the final design. As the design process progressed, there were more design choices to be made, such as specific interfaces between subsystems and dimensioning and specification of each individual feature. The selection matrices were again incorporated to ensure each subsystem helped the overall system reach its goals. For more information about each individual subsystem, consult the subsystem chapters.

Layout of System Level Diagram

Figure 2.6.1 shows a layout of the system-level design. This layout was used as a reference for inputs and outputs during the design process, to ensure that all subsystems are being designed correctly. This diagram demonstrates the facilitation of the inputs being converted into outputs, graphically.

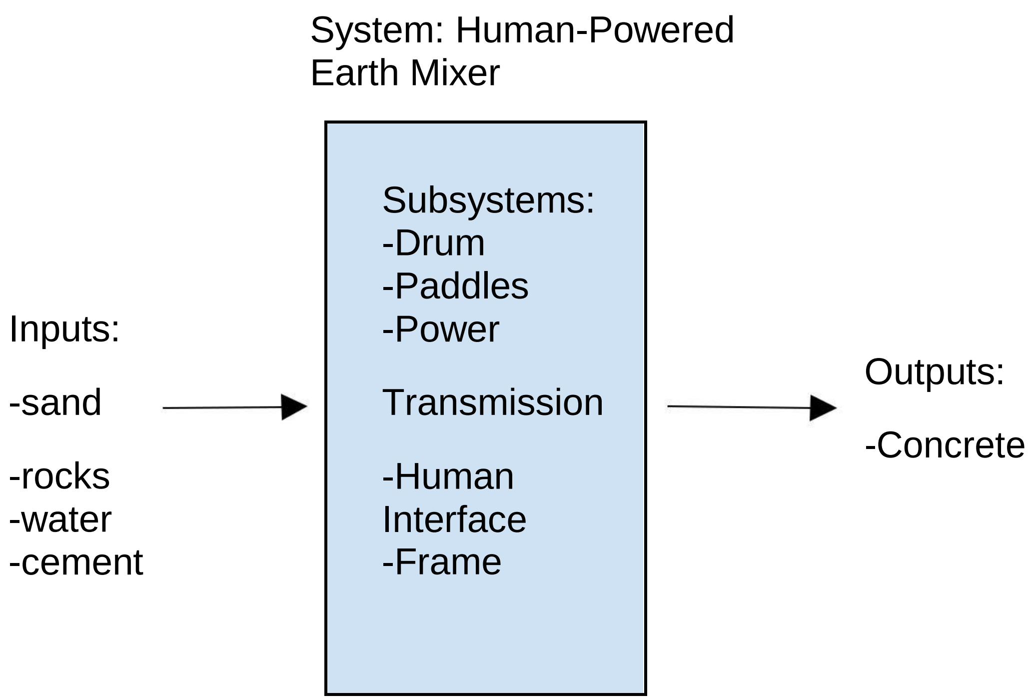


Figure 2.6.1. Layout of System- Level Design

Chapter 3: Operational Protocol

3.1 Project Constraints and Challenges

The project faced several unique challenges and design constraints, both technically and logistically, because of the customer's location in remote regions of Nicaragua. The most important constraint was in the lack of reliable electric power available to the mixer, once it is produced in Chinandega. Consequently, the greatest technical design constraint that faced this project involved transforming traditionally electrically powered components of a concrete mixer into a human-powered system. This constraint affected every subsystem of the design. In addition, the logistical challenges were equally significant. Many traditional materials and construction tools available to the team in Santa Clara, CA are not readily available at the Amigos for Christ workshop in Nicaragua. As such, the team had to design their mixer using local materials and tools available in this rural region of Nicaragua. This influenced the design process and prohibited the feasibility of many initial design options.

3.2 Design Process

Initially, each member of the group conducted separate research and produced three different designs that they felt would best solve the issue. In the following group meeting, there were more than 12 preliminary designs to evaluate. Then, as a group, three to four composite designs, as well as designs for individual subsystems, were chosen for further development. Each member created three to four different solutions for each subsystem. In turn, the subsystems were then evaluated for feasibility. In the end, the design chosen consisted of using an oil drum, chain drive, bicycle interface, and an X-frame. These are all similar design elements that were present in the initial sketches. However, after careful evaluation, these types of subsystems seemed to be the best options in comparison to the other ideas considered. The subsystems were evaluated using the concept scoring spreadsheets provided in Appendix D. The next phase of the design process included the specific CAD drawings of each of the subsystems. For sketches relating to this design process, see Appendix E.

3.3 Team Management

The team consisted of four members. All of the team members are senior mechanical engineering students. Each member had different strengths, and was given different responsibilities as shown in Table 3.3.1. During group meetings there was a designated time for disagreements between members to be discussed. These disagreements were settled through discussion and compromise, so that every team member could make their voice heard.

Table 3.3.1. Team Roles and Responsibilities

Team Member	Role and Responsibilities	Notable Skills
Connor McLoughlin	• Team Leader • Drum Designs	• Organization • Communication • Matlab
Nick Szychowski	• Prototyping Lead • Human Interface Design	• Proficient in Solidworks and Creo • Positive Attitude
Nathan Metzger	• Secretary • Meeting Minutes • Weekly Progress Reports • Frame Design • Presentation Lead	• Has Participated in Similar Projects • Communication • Calculation
Maddy Bustard-Gustafson	• Technical Expert • Power Transmission Design	• Finite Element Analysis • Proficient in Solidworks • Coding in C
All Members	• Research • Brainstorming • Calculations • Prototyping	• Mechanical engineering seniors • Machine Design • Research Expertise

3.4 Budget

The costs of building a concrete mixer in Chinandega have been divided into two main sections. The first section is the cost of materials for both the prototype, and the final design in Chinandega. A detailed budget is included in Appendix G.

The project received a total of $8500 in funding from the Roelandt's Grant, SCU School of Engineering Senior Design Funding, and Xilinx Grants.

3.5 Timeline

Below is an outline of the timeline for the winter and spring quarters. For a more detailed timeline, see *Project Gantt Chart* in Appendix C.

Table 3.5.1. Outline of Schedule for Final 6 Months

Deadline	Goal
End of Fall Quarter	• Second Design Iteration Completed • Finish Materials List
End of Winter Break	• Evaluate Second Design Iteration • Design feedback from Amigos for Christ
Week 4 Winter Quarter	• Complete Final Design • Complete CAD for Final Design • Begin ordering parts
End of Winter Quarter	• Parts Located and Ordered
Spring Break	• Begin work on Prototype
Spring Quarter	• Prototype Completed • Prototype Tested and Evaluated

3.6 Risks and Mitigations

One of the largest risks with this project was the group's original intention to travel to Nicaragua for implementation of the design. Due to time and communication constraints, the group was not able to travel. The mitigation for this risk was to provide a user manual to the group in Nicaragua, Included in Appendix C. This manual, along with the detail drawings, instructs the user on how to build and use their own HPCM.

Chapter 4: Drum Design

4.1 Introduction

The main functions of the drum are to contain and mix the components of concrete. The power transmission will rotate the drum in the frame, and this rotation will provide the energy to mix the materials. The drum will be comprised of two components. First is a cylindrical container making up the body of the drum. This part needs to be big enough to easily mix the target volume of 0.08 cubic meters. Next, a set of mixing blades fixed to the inside of the cylinder, to decrease the total mixing time. The mixing blades will facilitate mixing by causing the mix to be carried up the side of the drum during rotation and then fall back to the bottom of the drum. The location of the drum in the final design is shown in Figure 4.1.1 below.

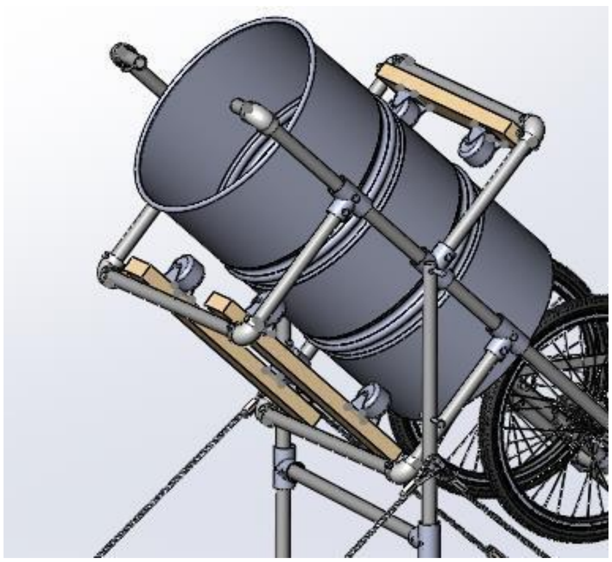


Figure 4.1.1. Drum Location in the Final Design

4.2 Options and Tradeoffs

The design team brainstormed different ideas for each of the drum components. The decisions for each of the components were made by comparing the benefits and drawbacks of each idea. On the next page, Table 4.2.1 shows the tradeoffs for the drum and mixing.

Table 4.2.1. Drum Component Options

Component	Idea	Benefits	Drawbacks
Main Mixing Chamber	55 gal Drum	• Large enough volume (about 0.2 m^3) • Standard part • Relatively inexpensive	• Hard to modify • Heavy when loaded
	Custom-made Cylinder	• Ideal dimensions • Choice of materials	• Expensive • More design work
	Beer Keg	• Easy to find	• Too Small • Hard to modify
Mixing Blades	Fixed inner diameter of drum	• Similar to commercially available concrete mixers • Can help to contain mix in drum	• Sturdy • Made of sheet metal/angle iron • Cheap
	Fixed to Central Shaft	• Central shaft could support drum	• More bending stress on blades • More difficult to design
	No Blades	• Ease of design • simplicity	• Less efficient • Less effective

The main mixing chamber for the design chosen was the 55 gal oil drum. The blades fixed to the inner diameter of the main mixing chamber were implemented to improve mixing. These blades are necessary to ensure that clumps of dry concrete do not form in the mixture. Dry clumps create significant weaknesses in the final product, as they do not allow all of the cement to cure.

4.3 Final Design

The main mixing chamber chosen for the design was the 55 gal oil drum. The paddles were made of angle iron. These paddles were fixed to the inner diameter of the main mixing chamber to improve mixing. CAD drawings for the mixing drum, including paddles, are provided below.

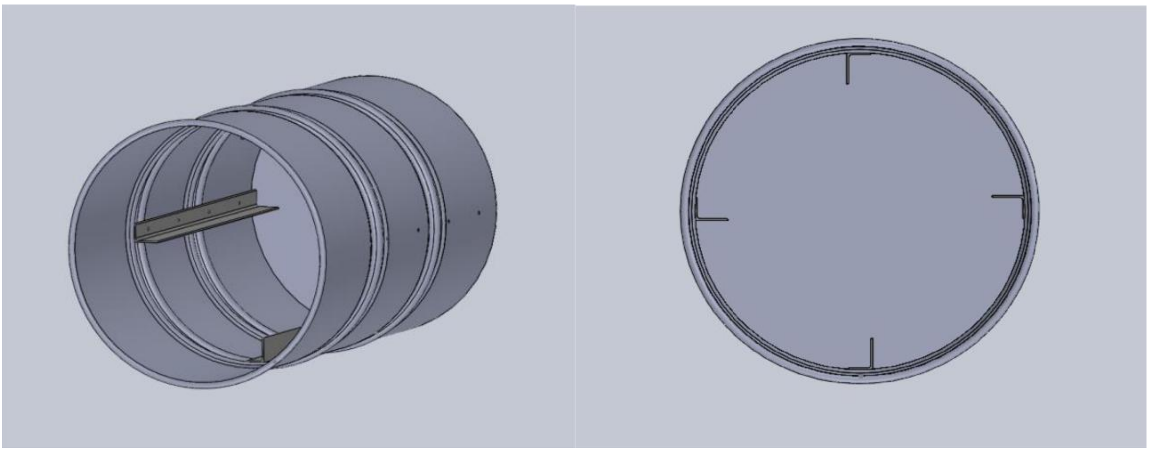


Figure 4.3.1. CAD of Mixing Drum

Because the drum was being powered by a friction drive, increasing the coefficient of friction between the drum and bike wheels would increase the efficiency of the power transmission. To accomplish this, sandpaper was added to the back of the drum. This was done because the team assumed that the coefficient of friction between sand paper and rubber would be higher than the coefficient of friction between steel and rubber. The sandpaper was fixed to the back of the drum using adhesive. Unfortunately, this bond was not strong enough. The sandpaper was ripped from the back of the drum as soon as testing began. Testing showed that once the drum was loaded, slipping was not a large problem. This mitigated the original need for sandpaper. Increasing friction between the drum and bike wheel was not abandoned completely by the team. However, the priority of this design change decreased after testing was successfully completed with the current drum. See Figure 4.3.2 below for a view of the concrete mixing process with the drum and mixing paddles.

Figure 4.3.2. Inside of Drum During Mixing

4.4 Tests and Verification

The main test that was performed for the drum was the mixing of material, with the results being largely qualitative. The results of these tests are summarized in Table 4.4.1 below.

Table 4.4.1. Results of Tests for Drum Subsystem

Goal	Result
Hold 0.08 m^3 of material	*Goal Achieved:* The drum was able to successfully mix 0.08 m^3 of concrete
Prevent formation of clumps	*Goal Achieved:* The resultant mixture was devoid of clumps of dry material
Prevent spilling of materials	*Goal Achieved:* All material put in as raw material stayed in the drum while mixing
Be easily rotated by user	*Goal Achieved:* See verification data in Chapter 8 for more details

4.5 Manufacturing Process

The drum was constructed in the Santa Clara University Machine Shop (See appendix A3 for manufacturing details):

- 1/4 inch holes were drilled in the 55 gallon oil drum using a hand drill.
- Holes were also drilled at the same distance apart on four pieces of angle iron.
- The angle iron was fixed to the inside of the drum with 1 inch long bolts. Quarter inch diameter inch nuts and lock washers were used in this process.
- Rubber washers were used as gaskets between the angle iron and the drum. The gaskets were included to reduce the likelihood of cement leaking out of the drum though these bolt holes.

Chapter 5: Upper Frame

5.1 Introduction

The upper frame of the Human-Powered Concrete Mixer serves three primary functions:

1) Maintains a stable axis of rotation of the mixing drum.
2) Ensures a stable contact interface between the back of the drum and the driving bicycle wheels.
3) Allows for quick and easy pouring of the mixed concrete out of the drum.

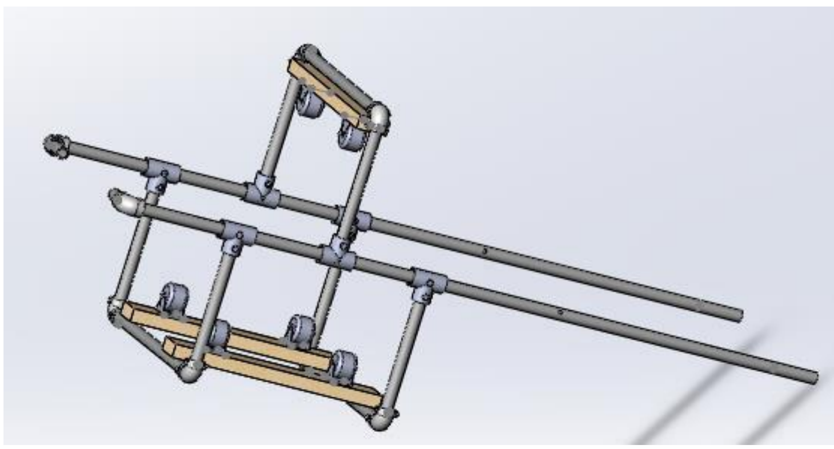


Figure 5.1.1. Isolated Upper Frame CAD Model

Figure 5.1.1 shows the CAD model of the upper frame before it is integrated into the full assembly. It features three U-shaped frames inside of which the drum smoothly and stably rotates during use. The U-frames feature a system of caster wheels, which fulfill the first two primary functions of the upper frame stated above. The design of the upper frame prevents movement of the drum, except for changes in pitch and rotation along its central axis. By limiting the drum to only two of six degrees of freedom, the upper frame ensures high functionality of the mixer's key processes.

The upper frame does allow the pitch of the drum to be altered, which is essential in order to facilitate the process of pouring out concrete once it has been mixed. The upper frame interfaces with the complete system at two pivot joints connecting the lower and upper frame. These pivot points rely on a standard rod threaded through holes on both the upper and lower frames. The upper frame can then be rotated around this rod by lifting the back handles. Due to the length of the long rails on the upper frame, there is a great deal of leverage during this process. As such, tilting hundreds of pounds of mix out of the drum and onto the ground becomes a one person job.

5.2 Material Options and Tradeoffs

Table 5.2.1 provides a simplified breakdown of the primary material options considered during the design process and the reasoning behind the final design decisions. It highlights the driving forces which went into the design and production of each of the different components of the upper frame.

Table 5.2.1. Material choices and Component Breakdown

Component Function	Alternative options	Rationale for Choice
Structural support members	● Aluminum Tube ● Wood ● PVC Pipe ● Galvanized Steel Tube	**Material Chosen: Steel Tube** ● Provides greatest strength ● Comparatively low cost ● Available in developing countries
Ensure stable axis of rotation	● Caster wheel assembly ● Primary axle	**Material Chosen: Caster Wheel Assembly** ● Low cost ● Easy to manufacture ● Available materials
Fastening primary support members	● Welding ● Standard Fittings	**Material Chosen: Standard Fittings** ● Low cost ● Does not require skilled labor ● Increases modularity ● Available in developing countries

As noted in Table 5.2.1 steel tubing was chosen for the primary structural members in the upper frame. A variety of options were considered; but, galvanized steel cylindrical tube was ultimately chosen as it provides the greatest combination of strength and cost efficiency of any of the options considered. Other important characteristics of galvanized steel tube are that it has more resistance to the elements. The mixer will remain outside, often subject to rain, so it is imperative that the frame be resistant to rust. Moreover, a cylindrical cross section was chosen over the square cross section initially considered, because standard fittings are typically more readily available for a low cost cylindrical tube versus other geometries. The fittings chosen were purchased from a global supplier to ensure that they could be shipped to rural communities all over the world, including Chinendega, Nicaragua.

The primary innovation of the upper frame is centered in the caster wheel assemblies, which maintain the axis of rotation of the drum. All commercial cement mixers use one central axle welded to the back of the drum in order to bear the load of the cement and rotate the drum at the same time. While effective, this requires extremely precise machining and expensive specialty parts, which are outside the manufacturing capabilities and budget of Amigos for Christ. Consequently, a caster wheel system was used to achieve the necessary functions of the upper frame. The caster wheels were screwed into pieces of 2x4 wood. The 2x4 was then attached to the horizontal members on the U-Shaped frames with standard U-bolts. A total of 6 caster wheels were installed on the upper frame. Four are located on the bottom half of the drum, in order to bear the majority of the load, while the remaining two help ensure the drum has no lateral movement and exclusively rotates about its free axis of rotation. The full caster wheel assembly provided a cost effective, yet, highly efficient mechanism for simulating a traditionally used back axle. Taken in its entirety, the upper frame, including the individual components described above, ensure that the drum can rotate smoothly and stably with hundreds of pounds of mix inside. Moreover, they allow this mix to be poured safely and smoothly out of the drum for use.

5.3 Manufacturing Processes

The upper frame was constructed in the Santa Clara University Machine Shop (See appendix A3 for manufacturing details):

1. The steel tube comprising the upper frame was cut using a horizontal band saw.
2. Holes were drilled into the tube using a drill press.
3. 2x4 wood was cut using a saw.
4. Caster wheels were attached using a drill

Chapter 6: Lower Frame

6.1 Introduction

The lower frame interfaces with the full assembly at the two pivot joints connecting the lower to the upper frame and serves two main purposes:

1) Supporting the weight of the drum when empty and when filled with raw material.
2) Bearing these loads in a safe and stable manner.

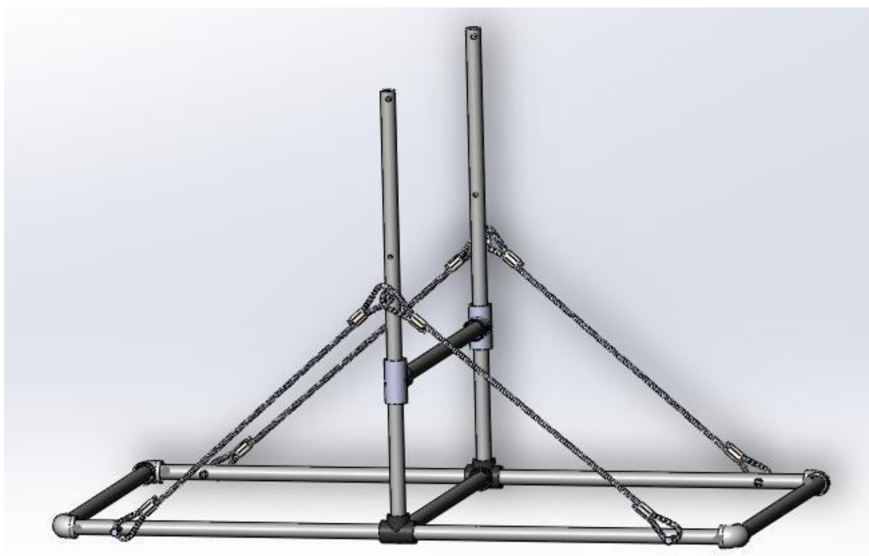


Figure 6.1.1. Isolated Lower Frame CAD Model

Figure 6.1.1 shows the CAD model of the lower frame. It features a base component designed to stabilize the entire mixer and prevent any possibility of it tipping over. Connected to the base frame are two vertical supports. These are the primary load bearers of the lower frame and are reinforced with steel cable in tension. The cable serves to minimize any vibration and ensure the structural integrity of the frame under any loads that could be applied during use.

6.2 Material Options and Tradeoffs

Table 6.2.1. Material choices and Component Breakdown

Component Function	Alternative options	Rationale for Choice
Structural support members	● Aluminum Tube ● Wood ● PVC Pipe ● Steel Tube	**Material Chosen: Steel Tube** ● Provides greatest strength ● Comparatively low cost ● Available in developing countries
45 degree tension members	● Galvanized Steel tube ● Stainless Steel Cable	**Material Chosen: Stainless Steel Cable** ● Low weight impact ● Provides tension support
Fastening primary support members	● Welding ● Standard Fittings	**Material Chosen: Standard Fittings** ● Low cost ● Does not require skilled labor ● Increases modularity ● Available in developing countries

As noted in table 6.2.1 and previously in Table 5.2.1, steel tubing was chosen as material for the primary structural members in the lower frame. The galvanized steel tubing chosen for the lower frame is identical to that used in the upper frame. All of the material characteristics of the cylindrical galvanized steel tube were essential for the lower frame to an even greater degree. Specifically, the strength of steel in compression was the primary desired attribute that drove its use in the lower frame. The two vertical supports are the two most highly loaded members in the entire system, so their ability to bear compressive loads was essential in order to maintain the integrity of the frame. Other characteristics, such as resistance to the elements, low cost, and worldwide availability, were qualities which were very desirable, just as with the upper frame.

An important manufacturing design change was the addition of tension members with 1/8th inch stainless steel cable. This was a change made on the manufacturing floor for the primary reason of weight reduction. An identifying feature of the human-powered concrete mixture is its mobility. Because it is essential that the mixer can be picked up and moved into a truck by 1-2 people, reducing weight wherever possible was essential. By swapping out a total of 10 feet of steel tube with cable a weight reduction of 17 pounds was achieved. Furthermore, the cable featured turnbuckles on all four segments.

Figure 6.2.1. Demonstration of a Turnbuckle *(Raleigh Design)*

Demonstrated above in figure 6.2.1. a turnbuckle is a standard component often used to connect two pieces of cable together and provide a tensile load to each. By tightening the turnbuckles on the HPCM, the steel cable was able to apply opposing tensile loads to each primary vertical support. This tensile load further increased the stability of these vertical members and reduced the lower frame's sensitivity to failure due to structural loads or vibration. Moreover the initial steel tubes were only able to provide a compressive support as there were no forces drawing them in tension. Therefore the turnbuckle and cable design change provided a much needed weight reduction, as well as structural improvements to the lower frame. These improvements allowed the lower frame to effectively withstand all standard loads applied in analysis and testing of the human-powered cement mixer.

6.3 Manufacturing Processes

The lower frame was constructed in the Santa Clara University Machine Shop (See appendix A3 for manufacturing details):

1. The steel tube comprising the lower frame was cut using a horizontal band saw.
2. Holes were drilled into the tube using a drill press.
3. The steel cable was cut with standard bolt cutters.
4. End clamps for the cable were crimped using a swaging tool.

Chapter 7: Power Transmission Design

7.1 Introduction

The power transmission system converts the energy provided by the operator into the rotational energy of the mixing drum. This is a vital part of the mixer since the project is primarily concerned with providing a mechanical advantage over hand mixing. The power transmission must provide enough mechanical advantage to the operator that it is easier to use the mixer than to mix with a shovel. The primary design concern for the power transmission was efficiency, namely, how effectively the user’s power output was converted into mixing concrete. Additional design concerns, such as manufacturability and cost, played a large role in the final design choice of a friction drive at the back of the drum.

7.2 Options and Tradeoffs

Table 7.2.1 shows the different ideas presented while brainstorming in conjunction with the benefits and drawbacks associated with each idea.

Table 7.2.1. Benefits and Drawbacks for Power Transmission

Idea	Benefit	Drawbacks
Chain Drive	• Chain is easy to acquire and replace • Able to reach desired RPM	• Becomes weaker when dirty • Weak in torsion • Must stay in same plane as the gear • Must be clean and well lubricated
Belt Drive	• Able to operate in torsion • Common part found in Kathmandu • Able to reach desired RPM	• Elastic could wear out and need to be replaced • Could less efficient
Friction Drive	• Easy to implement • Cheaper than other options • Custom parts unnecessary	• Need close tolerance • Concerned about upkeep (wear of tread) • Less efficient
Gear Train	• Standard ISO parts easy to acquire • Able to use different gears for torsional changes	• May be heavy and/or expensive • May be hard to replace if needed

The type of power transmission system used in the final design was a friction drive. This means that there is no positive engagement between the drum and the bike wheels. Instead, the power is transmitted by the force of friction alone. This type of system is far less efficient than a more sophisticated power transmission such as a gear train. However, it makes up for its inefficiencies by being very simple and cheap relative to more efficient systems. A friction drive could be easily implemented in a developing country. Engineers and operators in those countries would struggle to find the manufacturing capabilities and parts necessary to build a more complicated system.

7.3 Final Design

The friction drive designed for our machine uses bike wheels powered by a handle to spin the mixing drum in the upper frame. A Solidworks assembly of the power transmission is included below as figure 7.3.1. In this picture some elements of the upper frame have been hidden to give the viewer a better look at the system.

Figure 7.3.1. Solidworks Assembly of the Power Transmission

An important aspect of our design was to make the handle connected to the power transmission system power the drum both as the handle is raised and lowered. Being able to pump the handle and provide power both on the up and down strokes doubles the power output of the system. The component that allows this innovation is called a freewheel. This is a standard component on most bicycles. A diagram of a freewheel is shown below as Figure 7.3.2.

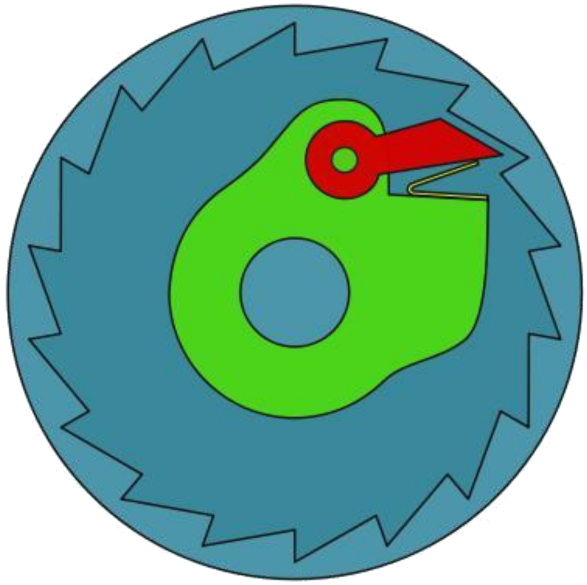


Figure 7.3.2. Diagram of the interior of a Freewheel

A freewheel transmits torque in one direction, and spins freely in the other direction. In the diagram above, the outer part of the freewheel would spin freely in the clockwise direction. In the counterclockwise direction the ratcheting mechanism would catch and transmit the applied torque to the central shaft. In our design, the handle pumped by the operator is connected to two freewheels. These freewheels are mounted to the bike wheels in opposite orientations. This design is what enables the mixer to be powered by both up and down strokes of the handle. The connection method is modeled after a bicycle tool called a chain whip. This means that a bike chain is wrapped around the sprocket and then pinned into a lever arm. This connection of the the freewheel to the ratchet handle is shown in Figure 7.3.3.

Figure 7.3.3. Freewheel Attached to Ratchet handle, Bike Wheel, and Upper Frame

7.4 Manufacturing

The power transmission was fabricated with the rest of the machine, in the Santa Clara Machine Shop. The main components of this subsystem were the freewheels, bike wheels, bike axles, bike chain, and angle iron. The machines used in the production of the power transmission were a horizontal band saw, and a drill press. In order to make the handle, four 5/32 inch diameter holes were made in one end of each piece of the angle iron. On the other face of each piece the angle iron, ¼ in holes were drilled for cross-members. Next, the smaller holes were used to pin bike chain around the freewheel sprocket. This interface can be seen above in figure 7.3.3. Bar stock cross members were bolted into place using the ¼ inch holes and 1 inch long bolts.

Chapter 8: System Integration and Testing

8.1 Introduction

After each subsystem had been created, they were each brought together to form the final concrete mixer. Before this was done, computer simulations were first conducted using finite element analysis software about the initial design and loading of the mixer. Because the mixer contained a large rotating drum, a theoretical vibration analysis was conducted to find the natural frequency of the filter. Once the computational analysis verified that systems integration would be safe, testing of the completed mixer commenced. It was imperative to conduct testing to be sure that the necessary specifications had been met. An experimental protocol was written to analyze which methods of testing would be the most productive in finding the efficiency and safety of the mixer. Finally, the results of the testing were collected and analyzed.

8.2 Simulations and Results

Both simulation and physical prototyped tests were conducted on the Human-Powered Concrete Mixer. First, computer simulations were performed using Abaqus. This was done by constructing a simple frame in Solidworks and uploading that to Abaqus. The original Solidworks frame could not be used with the student version of Abaqus due to the limit of elements available during the meshing process. The material properties were defined as of typical structural steel. The boundary conditions were defined to be fixed on the bottom-most beams since they are on the ground. The loading distribution can be found in the figure and table below.

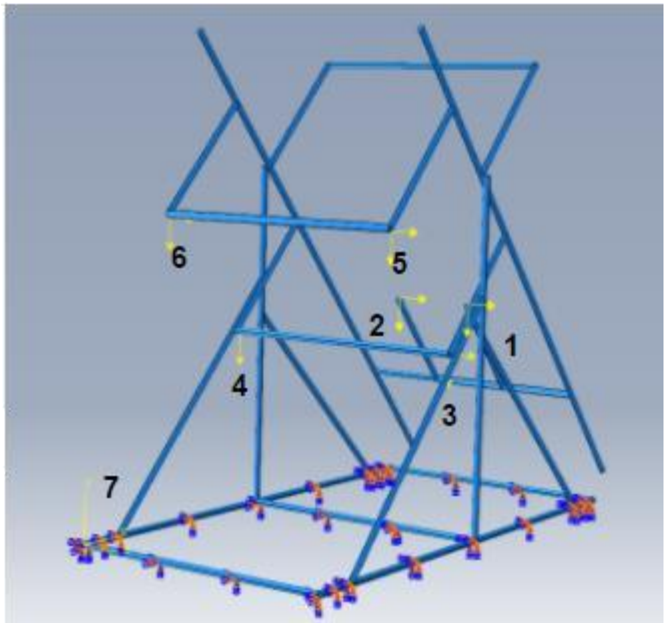


Figure 8.2.1. Load Distribution on the Finite Element Analysis Model Diagram

Table 8.2.1. Load Values for Above Diagram

Node	*Placement*	*Load (lb-f)*
1	Left Wheel	125
2	Right Wheel	31.2
3	Left Middle	62
4	Right Middle	16
5	Left Front	5.4
6	Right Front	5.4
7	Low Bars	Fixed

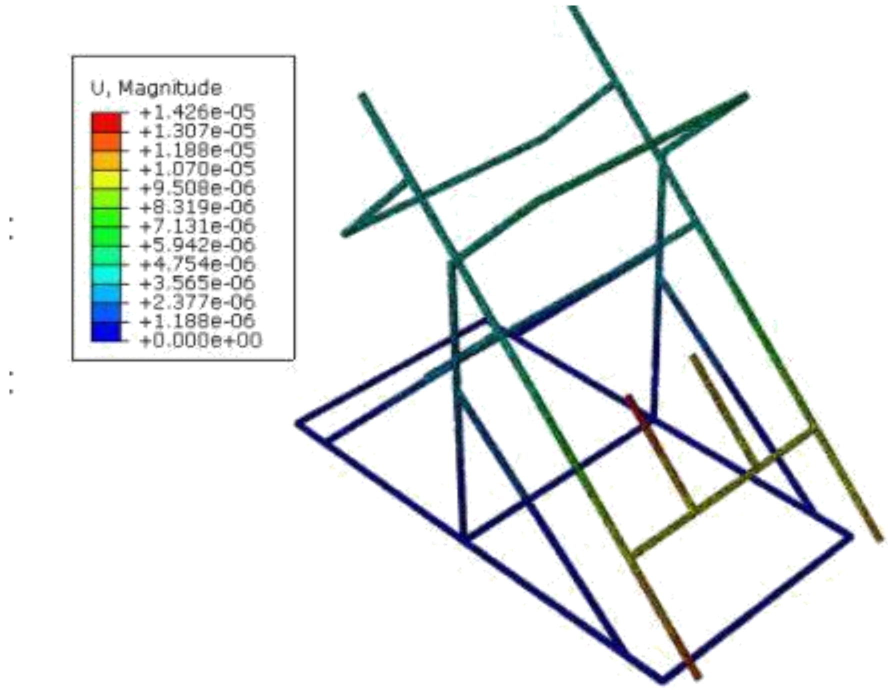


Figure 8.2.2. Loading Simulation Results

The results from this loading simulation were found to cause minimal amounts of deformation, less than 15 micrometers at the most when the typical amount of loads was applied, as shown above.

Next the vibrational analysis was conducted. This was done using a true wire frame with the same material properties and boundary conditions for the first simulation. The first five natural frequencies were found. To reach the first natural frequency, the drum would need to reach almost 700 RPM which is not possible using the human-powered mechanism designed for the scope of the project.

Table 8.2.2. Vibrational Analysis Simulation Results

Mode	*Natural Frequency (Hz)*
1	28.4
2	31.3
3	31.3
4	40.5
5	51.4

The finite element analysis simulation results showed low values for the deformations and a high natural frequency, so the design was concluded to be safe for assembly. However, there are some assumptions in the simulation, which could be adjusted for more precise results. While the lower bars on that would be on the ground were assumed to be totally fixed, there would actually be at least one degree of freedom. It would be possible for the mixer to slide on the ground. However, all of the resulting displacements and natural frequencies far exceeded the specifications.
Therefore, it was concluded safe to build and run tests in the Santa Clara machine shop.

8.3 Experimental Protocol

There are three main experiments that our team will run with our current prototype. The first experiment will be to determine the rotations per minute that is able to be produced by users of varying physical strengths and heights. The second test will be to determine the average rotations per minute when the drum has various weights and how long it takes to mix a full batch. The average was taken into account since there was a variation in the rotations per minute found by each member. In each of these experiments, one person will operate the mixer, while another observes the mix and determines when it is fully mixed. This is done to replicate the conditions under which the mixer is designed to operate. Once the concrete was produced, it was poured into cylindrical samples to examine the curing process. The main concern with the mixer was the consistency of the mixture that would be produced. By having many small samples, they can be examined to ensure that the final mixture is consistent throughout the batch.

Each of these tests helped demonstrate where different changes could be made to improve the effectiveness of the mixe. Most gas powered mixers rotate, on average roughly 20 RPM, therefore it is important to have a range of working RPMs that meet this specification. However, the ultimate specification will be the overall mix time. While RPMs are useful in determining an approximation for this calculation, the overall mix time is the specification that the consumer would actually cares about, as this will affect productivity.

8.4 Results and Comparison to Predictions

There were six samples created from a batch of concrete. The testing samples of concrete were cured in the SCU Civil Engineering labs. The purpose of this is to find how consistent the concrete is throughout the entire batch. All the samples from the same batch yield similar results, which shows that the mixer produces consistent results within the batch. Each concrete sample was able to be cured.

Table 8.4.1. Test 1 Empty Drum RPM Testing Results

Test	*Operator*	*Date*	*Result*
Empty Drum	Nathan	5/8/2017	19 RPM
Empty Drum	Nick	5/8/2017	12 RPM
Empty Drum	Connor	5/8/2017	19 RPM
Empty Drum	Maddy	5/8/2017	11 RPM

Table 8.4.2. Test 2 Average Weighted Drum RPM Testing Results

Test Weight (lb)	*RPM*
40	9.75
80	10.25
120	13.5
160	14.25

While the mixer at its full weight was turned at an average of 14.25 RPM, the concrete mixture was visibly shown to exhibit typical concrete properties after five minutes. This shows that although it did not reach the 20 RPM specification, it did still meet both the time, and number of operators specifications. Test 3 showed that, although the 20 RPM specification was not met, the mixer took roughly five minutes to create a consistent batch of concrete that was able to cure in a sample mold.

Using this analysis, there are various methods that could be implemented to improve the function of the mixer. While the RPM specification was not met, the mixer was found to produce concrete in roughly five minutes with only two operators. The RPM was 14.25 when the drum was fully loaded but the specification was 20 RPM. To meet this specification, a rougher surface may be attached to the bottom of the drum where it interfaces with the wheels. This would increase the amount of friction that is available and prevent slipping between the drum and wheels. It is assumed that by eliminating losses due to slippage, the mixer would reach 20 RPM. In addition, different paddle lengths could also be used in the future to actively determine the effects of the inner drum geometry on mix time.

Chapter 9: Costing Analysis

9.1 Initial Design Cost Analysis

A primary driving factor during the design process of the HPCM was ensuring that the total cost of producing the mixer was affordable for developing communities. Several of the initial iterations of the HPCM provided the necessary functionality; but all of these initial iterations were redesigned in part due to high costs. Consequently, the use of affordable standard parts was a emphasized in the final design. One design which faced serious consideration as the finalized HPCM design choice is pictured in Figure 9.1.1.

Figure 9.1.1. Feasible design that proved too expensive

This design featured a gear train featuring two specialized bevel gears in order to translate the torque from the bicycle’s natural rotating plane to the perpendicular rotational axis of the drum. The square cross section structural supports would also be fastened by welding instead of fittings. This initial design provided all of the desired functionalities necessary to meet the project specifications; however, large labor and specialty part costs ultimately defeated this design. Namely, the gear train and bevel gears required were quoted upwards of $300 alone and the wage of a professional welder is $60/hour or more. The estimated cost of this initial design was $1600, far beyond a reasonable price for the intended community for which it was intended.

These cost considerations and others drove a redesign resulting in the final design presented in this report.

9.2 Final Design Cost Analysis

Taking into consideration the cost burden of many of our initial designs, the final HPCM design was developed with a large emphasis on affordability. An important step transitioning from the initial design discussed in Section 9.1 to the final design was the removal of the expensive gear train. The gear train system was replaced with a friction drive featuring two standard bike wheels that were more affordable and easier to manufacture. In addition, standard cylindrical tube fittings with set screws replaced the expensive welds used in the previous iteration of the design. These fittings simply required a hex key and minimal technical skills to install, so they provided a more cost effective and simplistic solution. Cylindrical tubing replaced tubing with a square cross section due to lower costs as well. These design changes helped lower the cost of the mixer dramatically to a final cost of $544. This price reduction of over $1000 dollars from the previous design was extremely important in ensuring the final design could be implemented by Amigos for Christ in Nicaragua. Table 9.2.1 provides the respective cost of each subsystem

Table 9.2.1. Sub-system Cost Breakdown

Sub-system	**Cost (USD)**
Lower Frame:	133
Upper Frame:	191
Power Transmission:	124
Drum:	97
Total	544

Despite the frugally focused redesign of the HPCM there were still several relatively expensive components. The upper frame proved to be the most expensive subsystem in the design. This sub-system did play an important role however, as it maintained the axis of rotation of the drum and allowed it to tip to pour out concrete. This relatively large cost was acceptable as it replaced the central back axle typically found on commercial mixers. Welding a central axle to the rear of the drum was outside the scope of the manufacturing capabilities of Amigos for Christ, so the caster wheel and U-frame system was a necessary compromise. The power transmission proved to cost $105. Although this value is larger than the other components, it replaced specialty components and a specialized gear train so this price is much more affordable than the high cost of the initially considered gear train. The final design of the system is shown below:

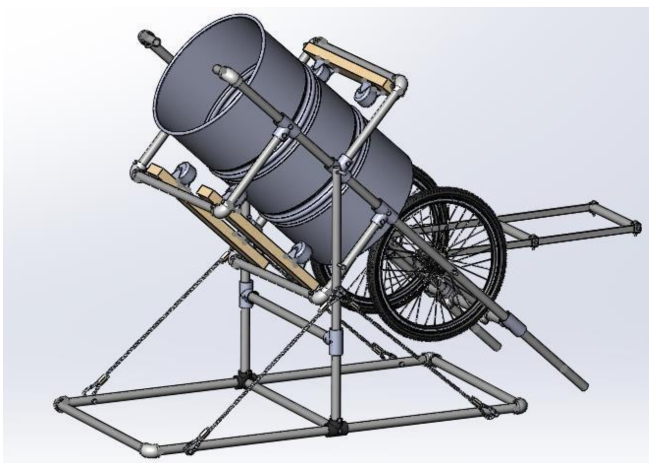


Figure 9.2.1. Final Design

Despite some of the relatively large costs of certain subsystems, the final cost, $544, of the mixer fell within the cost goals of this project. While $544 may appear to be a large sum for a struggling community, the mixer will be funded by Amigos for Christ and its donors. This charity frequently installs water filtration systems and buildings costing several thousand dollars, so $544 for a mixer to improve the efficiency of these large scale projects is comparably small. Amigos for Christ has a great deal of financial support from international donors, with a revenue stream typically between three and ten million dollars every year. The majority of the total financial support, typically upwards of 85% according to the financial statements of Amigos for Christ between 2010-2016, is directly used to support project services in Nicaragua. Project services primarily refers to programs for water and sanitation, education and nutrition, and economic development, which all require the construction of concrete foundations. Considering the fiscal resources of this group and the mixer's cost saving potential, the $544 price for the HPCM is quite reasonable.

9.3 Market Comparison

The cost of the human powered concrete mixer was compared to the costs of alternatives. Knowing the relative cost of the mixer should make it easier to assess the value of this machine. There are two possible alternatives to using a human-powered mixer. First is to use a portable gas-powered mixer. The second option is a portable electric mixer. The cost of these options has been compared to the cost of the HPCM.

The first alternative to the human-powered mixer would be to use a portable electric concrete mixer. These mixers range in price from 150 USD to over 1385 USD. This range is due to a variety of factors including durability, motor torque, max load, and mix volume. An example of a cheaper electric mixer is the Klutch Mini Portable Electric Cement Mixer. This mixer costs 150 USD and can be seen on the right side of Figure 9.3.1. However this mixer also has a very small mix volume of only 0.024 cubic meters. This is around one fourth of the volume of our mixer. On the more expensive side is the Kushlan 1000DD. This mixer has a 1 HP electric motor, a 0.14 cubic meter mix volume, and sells for $1385. It is pictured on the right side of Figure 9.3.1. The mixers on the lower end of this price range are cheaper than the HPCM. The more expensive mixers would be far out of the price range of a rural developing community. These electric mixers also have a major flaw for applications in areas where hand mixing is commonly used. The lack of a stable electrical grid would severely limit the usefulness of an electric mixer. The HPCM is comparable to these electric mixers in terms of function, but outstrips them in reliability in the target market.

Figure 9.3.1. Portable Electric Concrete Mixers

The other alternative to using a human powered mixer would be to use a portable gas-powered concrete mixer. The Kushlan Portable Gas-Powered Cement Mixer is an example of a mixer on the low end of the range for the mixers. It retails in America for $499, and is shown on the right side of figure 9.3.2. This mixer has a mix volume of 0.09 cubic meters, which is similar to the HPCM. On the other end of the price range is the Marshalltown MIX59289B. This mixer costs 3555 USD, has a mix volume of 0.15 cubic meters, an 8hp honda engine, and can be hitched behind a truck. A picture of this mixer is on the left side of Figure 9.3.2. The gas mixers on the lower end of the price range has comparable specs to the human powered mixer. However, these mixers are less mobile than the modular HPCM design. They also have the added recurring cost a gasoline, which would be a drain on the resources of a developing community.

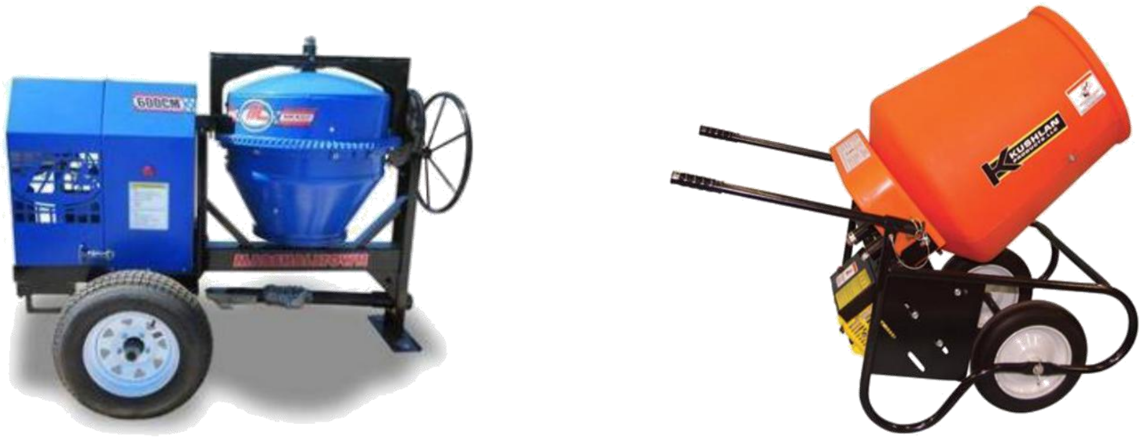


Figure 9.3.2. Gas Powered Concrete mixers

Chapter 10: Business Plan

10.1 Executive Summary

The Human-Powered Concrete Mixer offers a cheaper, more efficient, and more mobile method of mixing concrete in rural, developing areas. The HPCM will be made available through building kits, making the product easily accessible and manufacturable. By manufacturing and shipping all of the parts, we will lower cost by being able to buy and manufacture parts in bulk.
Similar to companies such as Ikea, offering our mixer as a “build-your-own” kit will reduce manufacturing costs and increase the availability of the machine.

10.2 Introduction

The Human-Powered Concrete Mixer (HPCM) is a machine that offers an alternative to the existing methods and solutions of mixing concrete for projects in remote, developing areas of the world. It serves as an improvement on the method of mixing with shovels, as it is more efficient, less time-consuming, and requires fewer manual laborers. It improves upon the existing solution of a gas-powered concrete mixer by reducing cost, improving mobility, and eliminating the recurring cost of using gasoline.

As indicated above, the target market for the HPCM is developing countries. More specifically, the HPCM is geared towards non-profits and social-enterprises that are currently working in developing countries. These mixers are not intended to be purchased and used by individual persons or families, but rather by larger groups that are working on larger-scale projects. The HPCM will help such groups have a greater impact over a wider area, as it will help them work more efficiently in remote and rural areas.

Based on current research, there is no reasonable competition for the HPCM. Other groups have designed human-powered mixers, but have yet to implement or move past the prototyping stage. As a result, the HPCM has the distinction of being the first to the market for an efficient, low-cost, mobile, and human-powered mixer. The main competition for the HPCM will therefore be the existing method, mixing by hand with shovels, as well the portable gas-powered concrete mixers.

10.3 Goals and Objectives

The main objective of the company is to help non-profits and social enterprises more effectively encourage long-term improvements in the standard of living in developing countries. This overarching objective was achieved through pursuing the following goals:

1. **Provide an low-cost, efficient, reproducible, and mobile product.** This goal is the primary responsibility of the Mechanical Engineering team. Throughout the design process, each of these design objectives was considered and re-evaluated in order to ensure that the product sold to non-profits and social enterprises is adequately fulfilling their needs for the lowest possible price.
2. **Choose partners selectively.** This goal is one that is, admittedly, difficult to stick to during the early life of a company as we strive to build brand recognition. However, this is integral to the company's objective of ensuring long-term growth. Long term growth in developing countries implies a long-term commitment on behalf of the non-profits or social enterprises. Therefore, the HPCM Company will strive to partner exclusively with groups committed to long-term growth rather than quick, temporary solutions.
3. **Make the product as easy to use as possible.** There are certain aspects of this goal that are inherent in the design process. However, this goal does not stop once the design has been completed, as it includes areas such as customer support, ease of manufacturing, and clarity and simplicity of the building manual. This is crucial so that groups in rural areas can construct and fix the machine without having to contact the company.

10.4 Key Technology

The main technology that differentiates the Human-Powered Concrete Mixer from other products on the market is its use of a human-powered power transmission. The power transmission acts as the interface between the user that is providing power and the drum, rotating the concrete. What is particularly innovative about the HPCM power transmission is its integration of a friction drive. In this system, the rotating bicycle wheels interact directly with the drum to make it rotate, rather than interfacing through a gear train, belt drive, or other similar power transmission. These bike wheels are combined with a chain whip, which connects the bike chain to freewheels on the bike chain. These freewheels are similar to those that allow a user to pedal backward on a bicycle without encountering resistance. The freewheels are paired in such a way that the user powers the drum both upstroke and downstroke. As a result, this combination of friction drive, chain whip, and freewheel provides a simple, effective, and efficient method of transferring human power to the drum.

10.5 Potential Markets

The main potential market for the HPCM is non-profits and social enterprises in developing countries. The first of these groups, Amigos for Christ, has already been identified, and was our partner throughout the design process. During this design process, Amigos for Christ mentioned that they often communicate with and collaborate with other non-profits, both in Nicaragua and other countries. As a result, they will provide an opportunity to spread our product to different groups and markets. One of the main advantages of our product is that it is adaptable to a variety of different markets due to its reliance on readily available parts. This adaptability will help the HPCM be used in new markets by allowing one model to be used across many different markets.

10.6 Competition

Currently, there are no existing direct competitors with the Human-Powered Concrete Mixer. Earth Block International (EBI) has designed three different models for a human-powered mixer, but none of these have yet to move to the prototyping phase. As a result, the two main competitors for the Human-Powered Concrete Mixer are :

1. **Mixing by Hand:**This is the current method used by many non-profit organizations and groups in remote areas. It is reasonably effective for small projects, but requires extensive time and labor for a unreliable product.
2. **Portable Gas-Powered Mixers:** Due to a lack of access to electricity, groups in remote areas are unable to use electric mixers, and therefore must rely on portable gas-powered mixers to complete their larger-scale jobs. Though effective, gas-powered mixers are expensive, require continual purchase of gasoline, and are not mobile or durable enough for incredibly remote areas that lack paved roads.

In summary, the Human-Powered Concrete Mixer can be compared to the competition as follows. The portable Gas-Powered Concrete Mixer that was selected as competition was the Pro Series 5 Cu. Ft. Gas-Powered Commercial Duty Cement and Concrete Mixer. This was chosen as the relevant competition due to the fact that is a lower-end model, meaning that the technical specs of the machine and the cost are more directly comparable to the HPCM. A comparison of the HPCM to the competition is listed in Table 10.6.1 below:

Table 10.6.1. Comparison of HPCM to competitors

	Mixing with Shovels	**Portable Gas-Powered Mixer**	**HPCM**
Initial Cost	$163 (cost of shovels)	$616	$544
Recurring Cost	-----	$70/yr	-----
Mobile	✓		✓
Reliable		✓	✓
Efficient		✓	✓
Easy to Use		✓	✓
Easily Fixable	✓		✓

10.7 Manufacturing and Production

Our manufacturing plan is modeled of the IKEA model, whereby we would provide kits with instructions for each customer to build. In order to successfully implement this system, we plan on purchasing raw materials in bulk and making all necessary modifications (cutting, drilling holes, deburring, etc.) in our machine shop. In order to be able to fulfill the anticipated demand for the product while minimizing costs for inventory space, we hope to store 10 pre-boxed mixers, 10 sets of completed parts, and enough raw materials to produce 10 mixers in our warehouse at any given time.

Once we have completed modifications to parts, we will send the boxed kits to the customer with a set of instructions. This set of instructions will clearly detail how to construct the mixer from the given parts using only an Allen Wrench (provided with the kit).

By eliminating the need for finalized construction and shipping of a completed mixer, we will be able to provide a cheaper product to the user, by. We will also make the product more accessible, as kits will be more easily shipped to developing countries than fully-made mixers would be.

10.8 Product Cost and Price

As was briefly mentioned in the Competition section above, the cost of the prototype of the HPCM is $544. As this was a prototype, costs were not minimized as much as possible, such as with bulk pricing and shipping. A brief summary of parts that will be made less expensive through bulk pricing is shown in Table 10.8.1 below:

Table 10.8.1. Summary of Cost Reduction through Bulk Pricing

Part	Cost for Prototype	Bulk Pricing	Cost saved per Mixer
Steel Tubing	$3.21/ft	$2.27/ft	$47.10
Bicycle Wheels	$51.40/wheel	$36.14/wheel	$30.52
Caster Wheels	$9.25/wheel	$5.40/wheel	$23.10
Angle Iron	$5.63/ft	$3.45/ft	$13.43
			$114.12

As a result, we expect the cost of each mixer to decrease to around $430 when produced using bulk pricing and shipping for materials alone.

As was mentioned in the manufacturing section, it is expected that the demand will require materials on hand to produce around 30 mixers at any given time. As of right now, the assumption is that the four team members will be the employees for the company. Table 10.9.1 below summarizes our assumptions made in order to determine our break-even cost for the mixer.

Table 10.9.1. Analysis to Determine Break-Even Cost

Category	Cost per unit	Total Cost
Initial Materials	$430	$12,000
Space Requirements	------	$3,000/month
Personnel	$2,000/month	$8,000/month
Equipment	------	$2,500
		$27,500

In order to offset our monthly expenses for salaries and cost for renting space to store and manufacture, we estimate that we will need to sell 50 units per month, with each at a profit of $220/unit. As a result, we plan to sell the HPCM for $650/unit. Though this is slightly more expensive than the cheapest portable gas-powered mixers, the additional $35 is warranted due to the fact that HPCM does not require continual purchasing of gasoline, and that the HPCM offers a greater mobility than a gas-powered concrete mixer.

10.9 Services and Warranties

The main services and warranties provided by the company are as follows:

1. **One-year Warranty:** The company will accept responsibility of the failure of the machine due to any faulty part within the first year. User-incurred damage (improper use of machine, dropping, lack of care) will not be covered by this warranty.
2. **Repairs and Customer Service:** Due to the nature of the company, the HPCM company cannot personally service all sold machines. However, we will establish a customer service and support network that can help identify and solve issues with manufacturing and use of the machine as they come up.

10.10 Financial Plan

The expected business plan for the HPCM company is to start by producing and selling 50 units a month for the first 2 months. From there, production will increase by 10 units a month, every two months, until 100 units are produced and sold each month.

Chapter 11: Engineering Standards and Realistic Constraints

11.1 Manufacturability

The manufacturability of a machine is a constraining factor in how widespread its effectiveness will be. Especially in the area of design for developing countries, manufacturability must be a top priority due to the difference in manufacturing capabilities present in the target market. For this reason, an extreme emphasis was placed on our design to limit the amount of precise manufacturing and advanced machining that was necessary to produce the Human-Powered Concrete Mixer.

For our design in general, this meant choosing parts that were readily available and did not require extensive manufacturing to be used in the machine. Examples of this can be seen in Figure 11.1.1, and in Table 11.1.1 below:

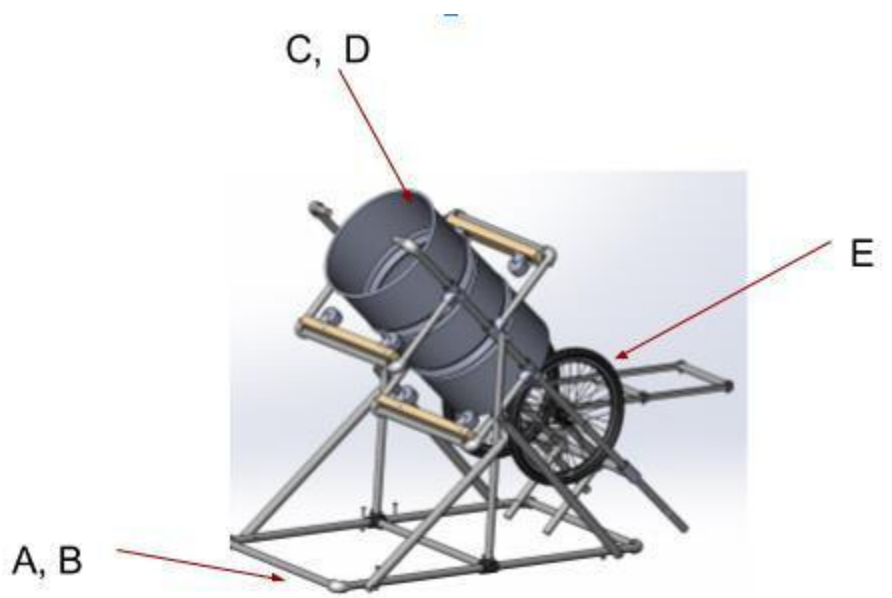


Figure 11.1.1. System Overview

Table 11.1.1. Examples of Material Choices Made for Manufacturing

Part	Material	Alternative(s)
A	Cylindrical Steel Tubing	Square Tubing, Aluminum
B	Set Screw Fittings	Bolted Holes, Welding
C	55-gallon oil drum	Self-Manufactured Drum
D	Angle Iron Paddles	Self- Manufactured Paddles
E	Bike Wheels	Gear Train, Bevel Gears

In the design of the frame, it was determined that cylindrical steel tubing was the best choice for manufacturability, due its availability and relative ease of use. The alternative of square tubing would have been more difficult to build with, especially considering the fact that it would have required welding joints. Welding is an expensive process because it requires highly skilled workers, and is not widely available in developing countries lacking consistent access to electricity. These difficulties with welding led the team to decide on set screw fittings instead of welded connections.

As mentioned in Chapter 4, one of the early options for the drum subsystem was designing and manufacturing our own drum. Due to the desire to make the design available to as many developing countries as possible, this option was avoided in favor of a 55-gallon oil drum, as these are pre-fabricated. A similar choice was made when choosing the paddles that would be used inside the drum. Though self-manufactured paddles would have given the opportunity for improved efficiency in mixing, the obstacle of manufacturing led the team to select angle iron for the paddles. This provided a suitable alternative that also eased the process of manufacturing.

The last main subsystem that was affected by manufacturing necessity was the power transmission. Rather than using more traditional power transmission systems, such as a gear train or belt drive, the team elected to use a friction drive powered by bike wheels and a ratcheted handle because it used the least parts and required the least high-precision manufacturing. In general, high-precision manufacturing with tight tolerances was avoided as much as possible throughout the design process. The main goal of this was to make the machine available to groups that do not have access to high-precision manufacturing tools, such as mills and lathes. In order to accomplish this, the following steps were taken:

1. **Manufacture with the least precise tool.** In our prototyping, we used the least precise tool that was possible, in order to ensure that our prototyping process most closely matched the process that would be available in developing countries.
2. **Choose parts that eliminate manufacturing.** The frame is the best example of this, as welding and bolted holes were largely eliminated in favor of fittings with set screws.
3. **Simplify the design.** Throughout the design process, a large effort was made to eliminate aspects of the design that would require high-precision manufacturing. These were replaced with relatively easy manufacturing processes, such as drilling with a hand drill or drill press.

In general, the manufacturability of the HPCM was of utmost concern due to our target market of developing countries. By choosing easily manufacturable parts, adapting existing parts such as bike wheels and oil drums, and minimizing high-precision manufacturing, the HPCM was designed to be available to a wide range of regions with limited manufacturing processes available.

11.2 Environmental Impact

The importance of environmentally-conscious design was a consideration throughout the design of the Human-Powered Concrete Mixer. While an important consideration in any design, environmental consciousness was especially applicable to the Human-Powered Concrete Mixer due to its association with Amigos for Christ and the Santa Clara University School of Engineering, both of which hold environmental impact as a high priority. Manufacturing concrete and the environmental impacts of physical mixing the cement, aggregate, and water are usually some of the most environmentally damaging processes on a construction site. The Human-Powered Concrete Mixer intends to use local and standardized materials in order to create a more cost-effective design, and the use of these local, readily available materials is an improvement, environmentally, on alternative methods.

Current concrete construction that utilizes gas-powered mixers contributes significantly to greenhouse gas emissions. For reference, a study done on the Portland Cement Concrete Pavement in China was used as a case study. It was found that approximately 92.7% of the greenhouse gases related to concrete production originated during the raw materials phase. While the Human-Powered Concrete Mixer does not explicitly address this issue, the target location for this product intends to use primarily locally sourced materials that will aid in this effort. The mixer will address the manufacturing of concrete and the correlative greenhouse gas emissions due to its substitution of human power for gas power. In the study, it was found that for every 3055 cubic meters of concrete produced, 600 tons of carbon dioxide are emitted due to manufacturing alone.

This study was conducted with diesel, industrial equipment. In practice, this means that the Human-Powered Concrete Mixer must produce around 60,000 loads of concrete in order to have saved 600 tons of carbon dioxide emissions. Though this is a relatively small environmental impact, it is appreciable over the life of the mixer. In this way, the greenhouse gases associated with the mixer will be tied to the production of the steel tubing and other materials used.

11.3 Sustainability

Though sustainability and environmental impact are often considered to be the same, they are in fact separate ideas, with environmental impact being a subset of sustainability. For this project, the team was concerned with sustainability in the following contexts:

1. *Environmental Impact:* For more information about environmental impact, see Chapter 11.2.
2. *Sustainability of Relationships with Communities:* One of the main facets of Amigos for Christ's mission statement is to build long-term, sustainable relationships with their community partners, especially by "giving away," but doing projects alongside the

community. For our project, this meant that we had to design a product that was intuitive enough to be used by any community member.

3. *Societal Impact:* Though a solution may be environmentally impactful and help foster long-term relationships, if it does not improve quality of life it is not sustainable. Chapter 11.4 below outlines in more detail what some of the ethical concerns were in this project, and is largely related to the ways in which societal impacts were measured from the project.

11.4 Ethical Considerations

At the initiation of this project, the primary guiding ethical standard was the UNICEF Universal Declaration of Human Rights, specifically Article 25, which states that "Everyone has a right to a standard of living adequate for the health and well-being of himself and his family, including housing." This statement was especially relevant in Takure, Nepal, where 98% of homes were either destroyed or severely damaged during the Gorkha Earthquake of 2015. A lack of government aid and assistance following this natural disaster created the housing deficiency which exists today. The only source of real support comes from Conscious Impact, a social enterprise organizing reconstruction with Stabilized Compressed Earth Blocks (SCEB). We found that the limiting process that could be modified to expedite the reconstruction process was to mix the material before compression into blocks. The current method is not only slow, but physically arduous, as community members mix the earth batches on the ground with shovels. As a result, the initial ethical justification for our project was to ensure that a fundamental human right was being met for community members in Takure, Nepal. Following this project initialization, there have been two main categories of ethical decisions. The first of these was our own team partnerships and organization. The second was the ethical concerns tied to design considerations and decisions.

Ethics and Project Partnership

The first category involved one major decision, which was to choose our team partnership. Our initial plan was to work with Conscious Impact, located in Takure, Nepal. A representative from this group contacted our team, asking us to design a human-powered concrete mixer to help speed up the process of rebuilding in the wake of the Gorkha Earthquake of 2015. After working with this group for about 4 months, we were contacted and told that they thought the project was no longer feasible; yet, they wished to use our funding to buy more raw materials. At this point we were left with an ethical dilemma. We felt that we had designed a product that could substantially improve the lives of many Nepali people; but, to do so, we would have to work with a group that did not seem to have our best interests at heart, causing us to question their intentions in Takure as well.

In order to devise a solution to this problem, we consulted a number of resources. The first was the Markkula Center for Applied Ethics *Framework for Ethical Decision Making.* From this, we realized that we had to recognize our ethical issue. In this case, the issue seemed to involve a decision between "two bads." In one scenario, we would be working with a group that now seemed to have questionable legitimacy and methods. On the other, choosing to not work with the group would negatively affect the people of Takure.

At this point, we realized that we needed to know more about the group and their credibility, in order to ultimately determine if we could further develop our relationship as partners. Unfortunately, conversations with different people yielded drastically different opinions of the group. A professor in the School of the Engineering informed us that, she had worked with the group in the past with no issues of any sort. However, another senior design team working with Conscious Impact informed us that they had received a similar email asking for funding, in lieu of the original project. It became clear to us that there were three parties that had a significant stake in the outcome of the project: ourselves, Conscious Impact, and the people of Takure. Of these three, the needs of the people of Takure far exceeded those of the others. This project was not intended to benefit us in any way from the start, and was only intended to benefit Conscious Impact by reinforcing their efforts to improve the lives of the people of Takure. Further consultation with team members, advisors, and members of Conscious Impact showed three clear paths: continue working with Conscious Impact, cut ties with Conscious Impact and continue the project in the hopes of later use, or cut ties with Conscious Impact and attempt to work with a different group instead.

At this point we decided to evaluate the options at hand. From a utilitarian point of view, working without a partner, either Conscious Impact or a different third party, would be the weakest of these three options. Without a partner community, the project could not make any notable impact. Looking at the issue through the perspective of the Rights approach, with a focus on the rights of the people of Takure, choosing to cut ties with Conscious Impact would not be an ethically sound choice. Our project was designed to help improve living conditions in Takure, and without it, this process would continue at its current rate and negatively affect the community. As a result, choosing not to work with Conscious Impact would not help ensure that the people of Takure were living dignified lives. The third ethical lens that was consulted was that of Virtue. We determined in our team that continuing to work with Conscious Impact would not be in line with the type of engineers, and people, that we want to be. Working with a group that would mistreat its associates was not in line with how we would like to act in the professional world, and was also in opposition to the ASME Code of Ethics, specifically statute 6, which states that engineers shall associate only with reputable persons and organizations.

Having considered these facts and the possible outcomes, we decided that our best course of action was to pursue a new partnership with a different group. Fortunately, we were able to find a group, Amigos for Christ, in Chinandega, Nicaragua could use our project. From all three ethical lenses, this was, at the very least, an acceptable option. From a utilitarian point of view, the most good was being done, because the project would be applied in an application meant to improve the lives of those struggling to live in developing countries. From the Virtue perspective, Amigos for Christ's attitudes towards working in and with communities were much more in line with our own. They see themselves as partners and peers with, rather than a "saving force" for, the people of the community that they aim to help. The most difficult aspect to consider was the Rights approach, and considering the rights of the people in Takure. We cannot definitively say that we acted in the best interest of the people of Takure, for whom the project was initially intended. However, we believe, through conversations with others, that if we had chosen to continue working with Conscious Impact, the living situations of those in Takure would not have been substantially improved, due to Conscious Impact's unwillingness to use the new product.

As a result, the rights of the people of Takure were neither positively nor negatively affected, while the rights of the people in Chinandega were positively affected, as they will be receiving the benefits originally intended for the community of Takure. We also determined that working with Amigos for Christ would continue to advance their Universal Human rights, by providing access to feeding centers and improved education facilities, and therefore a reliable source of food (Article 25) as well as to education (Article 26).

As a result of this decision, we were able to choose a path that would be rewarding not just for us, but for a third party. We also learned the hard lesson that sometimes it is necessary to cut ties with an organization if they are not holding their end of the deal or acting in a way that will benefit all parties.

Design Choices and Ethical Considerations

Following our choice of partners, we were required to re-design our project for different constraints, a process that often brought up its own ethical issues. One of the ethical issues that became apparent, was how to ensure sustainable growth and not just a short-term fix. We quickly realized that the most obvious solution to this building problem would simply be to provide a gas-powered mixer. Despite this initial thought, we realized there were a few issues, specifically the cost, environmental impacts, and dignity of persons involved. The cost of a portable concrete mixer is prohibitive for individual communities to purchase and use in Nicaragua. In addition to the down payment, long term costs such as those for maintenance and gasoline would rapidly exceed the budget of the construction effort. We also discussed the environmental impacts, specifically that using gas-power where human power is available, is not the most sustainable option. Finally, simply presenting a gas-powered mixer to a community undermines the dignity of individual persons in that community, as it implies that we, as the "givers" of the mixer, are in some way better because we are able to do things *for* the community.

In order to understand the importance of ensuring long-term growth in Chinandega, the team looked at how other nonprofits have dealt with this issue, and found a common methodology. The key is to work *with* communities and not *for* them. Ethically, this distinction is important, because empowering local communities to help themselves by providing the necessary equipment for growth, rather than creating a donor-recipient relationship, insures that the dignity of those in the community is upheld. In practice, these ethical considerations implied that the team had to manufacture a product that could be used by the community, without creating a dependence on foreign aid. Specifically, the mixer had to be:

1. *Easy to Use:* The mixer had to be easily operated, so that community members could use the machine without relying on many members of the group.
2. *Durable:* The design must be capable of extended use. Its use will span the duration of the rebuilding process, as well as allowing for construction of new buildings or repairs.
3. *Easily Manufacturable:* If people in Chinandega decide another mixer would be beneficial, the machine must be easily manufacturable by people with little to no manufacturing experience.

The design considerations above are not an exhaustive list; but, they are included to represent the type of design decisions and tradeoffs that were made throughout the design process. All of the design subsystems were subjected to the ethical decision making process of weighing the rights and necessities of the parties involved, as illustrated below:

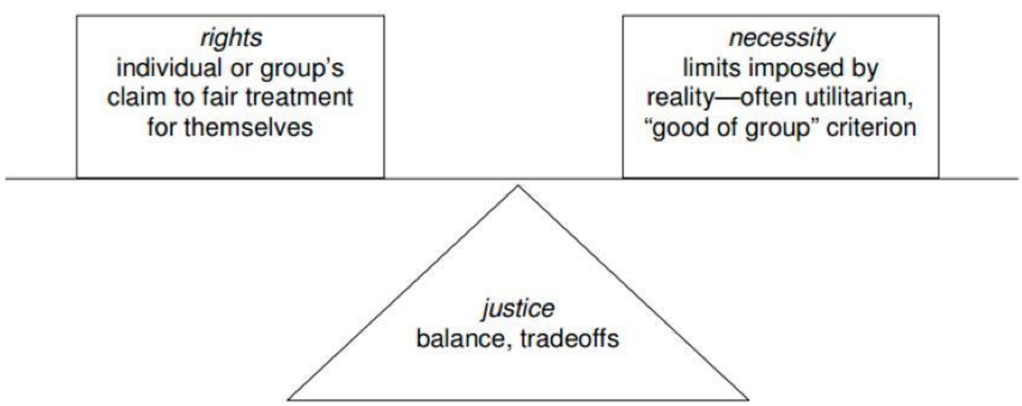


Figure 11.4.1. An Ethical Decision Making Tool (Riccomini)

Through this design process, it was important to consider the rights and necessities of the community in Chinandega, as well as the rights and necessities of the design team and Amigos for Christ. Due to the nature of this project, the needs of the community of Chinandega took precedent over the team's own needs. However, it was still important to subject every design decision to this ethical decision making schema. As a representative case study, the design process for the human interface will be discussed below.

The power transmission had three main options for design: a lever arm, a turning wheel, and a bicycle. There were certain engineering considerations that played a role in our final decision, such as size, available power output, and cost of each system. While there were strengths and weaknesses to each of these design options, each of the three proved to be viable. We therefore turned to an ethical lens to choose the right design choice, using the balance of rights and necessities in regards to our three design criteria listed above, and ranking each of three components from best (1) to worst (3) in each category, as shown in Table 11.4.1 below:

Table 11.4.1. Ranking of Relevant Categories in Ethical Design Decision

	Lever Arm	**Turning Wheel**	**Bicycle**
Ease of Use	2	3	1
Durability	2	1	3
Manufacturability	2	1	3

Despite being a useful exercise, this did not give us a clear result, as no option clearly excelled above the others in all categories. Therefore we resorted to weighing the rights and necessities of each group involved, and determined that the ease of use and durability were the most important design aspects, in regards to the rights of the people of Chinandega. A product that was not easy to use would not improve their standard of work. Moreover, a product that was not durable, would not provide long-term sustainable growth. As a result, the ethical considerations, in combination with the engineering constraints, led us to choose the Lever Arm as our human interface.

As can be seen in our project, partnership, and design choices, our project extends beyond simple technical issues and has direct ethical implications. By choosing a project that would advance universal human rights and choosing to partner with a group that would most effectively implement that design, we have been able to positively affect the lives of the people of rural communities in Chinandega.

11.5 Health and Safety

Of particular importance when designing a human-powered machine is the health and safety of the user. The main concerns that were addressed in the design process are listed below:

1. *Rotating Parts:* Rotating parts pose a threat to users because they can draw the user into the machine. In this design, there were four main rotating parts that were a concern:
    a. *Drum:* The drum rotates as it mixes material, and is by far the heaviest rotating object in the machine. To mitigate the risk of the user interacting with drum while rotating, the mixer was designed to have the drum away from the user while they are mixing the material. Special care in design was also made to ensure that drum stays stationary while rotating.
    b. *Upper Frame:* The upper frame rotates while dumping the mixed concrete, so it was important to provide a way to ensure that the user would not be in danger while the upper frame tilts. To ensure this, the handles to tilt the frame were placed 3.5 ft away from the axis of rotation of the upper frame, ensuring that the user would not be drawn in by the rotation.
    c. *Bicycle Wheels:* An earlier design option had the user rotate a handle connected to the bicycle wheels, rather than cranking a lever handle as in the final design. This would have posed a greater threat to the user being drawn into the bicycle wheels, so the hand crank was chosen instead.
    d. *Freewheels:* The freewheels still rotate, but pose less risk than a typical gear train. There is only one sprocket, and that it is covered by a bike chain. This limits the safety risks present in this aspect of the design.

2. *Weight while carrying machine:* The modular design of the HPCM allows users to carry the subsystems of the machine. Any situation that requires a user to carry and move weight poses a safety risks. Due to this safety risk, the weight of each subsystem was reduced as much as possible, and made easier to carry when possible.
3. *User Ergonomics:* The last health issue that was a main concern was the user ergonomics, or how the user interacts with the machine. Two main steps were taken to improve ergonomics. The first was to reduce the amount of power that had to be supplied by the user by providing a mechanical advantage. The second was to implement an easy to use and intuitive handle.

Chapter 12: Summary and Conclusions

12.1 Overall Design

While gas-powered concrete mixers are commonplace in the United States, it was a challenge to design a comparable modular, human-powered mixer. The human-powered concrete mixer was designed and built to be implemented in rural areas of developing countries. This meant that the mixer needed to be both made of readily available materials, and easy to construct. The frame was made of steel tube, which were connected using fittings. The mixing chamber was a 55 gallon oil drum that was modified with angle iron mixing paddles. The power transmission was built using bike parts, steel barstock, and angle iron.

The overall design of the mixer underwent many design changes before the final prototype was constructed. The most prominent being the power transmission. The original design included a bevel gear pair and gear box. However, that design was too expensive to be implemented in developing countries. The power transmission system was changed to a simple friction drive in order to make the machine as inexpensive as possible. This design cost significantly less and includes fewer pinch points. While there are the rotating ratcheting gears, they are safer due to distance from necessary operations, like pumping the handle. The frame was designed with the aim to stabilize the entire mixer but use minimal weight. To do this, finite element analysis was used to verify the design would safely hold, both in static and vibrational failure. However, the boundary conditions of this analysis included overconstrained sections, where the mixer meets the ground. It was assumed that this was totally fixed. Therefore, to improve upon the simulation before design, the boundary conditions would be adjusted for some sliding on the ground. Finally, the refurbished oil drum worked as an effective drum for mixing. This was a useful decision since almost every country uses them. Ultimately many design iterations occurred before the mixer was produced, but it may be beneficial to revisit elements of the design to increase efficiency.

12.2 Next Steps

Although the project overall met the most critical specifications, there could be other steps to take to improve upon the design and analysis. One of the tests involved creating a full batch of concrete and curing the samples. Therefore, it could be helpful in the future to conduct strength analysis testing on those samples. Then, the consistency of mix will be more thoroughly examined to verify the strength of concrete produced is consistent. In addition, blade geometry and friction drive testing could be beneficial in providing a more thorough concrete mixer design. While the mixer took roughly five minutes to create a single batch of concrete, this time could potentially be reduced using different blade geometries. The blade geometry is one of the more simple adjustments that could be made to improve the design. The angle iron blades would be fabricated and then replaced inside the drum. The concrete would be mixed and timed to determine which of the blades produced the fastest, and strongest concrete. Similarly, it was found that a lot of energy loss occurred through friction drive when the drum was not loaded fully. Often, the wheels would slip against the drum instead of turning it. However, the overall RPM may be increased if there is more friction between the drum and the wheels. One way of doing this is to change the surface by painting it with epoxy and adding sand. Having a rougher surface would decrease the amount of slipping which would aid the RPM. These are some of the ideas of how to improve the concrete mixer, should the design be revisited.

The next steps the team is taking includes putting together a manual for Amigos for Christ and sending it to the organization, who can translate it into Spanish. The mixer was designed for this purpose, and therefore, can be reproduced in Nicaragua. All of the materials necessary are either readily available or can be easily shipped. Similarly, the mixer was designed with parts which need minimal fabrication. This was considered to be one of the most ethical design choices so that, if necessary, the mixer may be reproduced easier. This is one such example of how design choices had to be made with respect to the target community.

12.3 Lessons Learned

Overall, this project has reinforced critical concepts of the university's undergraduate curriculum, which are not necessarily taught in the classroom. Nevertheless, these are important skills necessary to function as an efficient engineering team. It has been imperative to have effective engineering communications, multiple design iterations, and the ethical challenges for designing for a developing community. This is the first time that the team had operated with other organizations outside of SCU, so it became very clear that clarity in working with other people in terms of design specifications and deliverables is extremely pertinent. For example, this was important for the HPCM team to understand what materials and manufacturing processes were available when conducting design iterations.

This project showed that it is important to stay patient and continue designing. Unlike other projects done in the undergraduate level, this year-long project needed many drastic redesigning efforts. This was primarily due to the changing constraints and design variables of the project. However, with the changing of organizations, the mixer underwent design changes that were deemed the most effective for the target client. Different communities had different needs. For example, the community in Nepal did not need a mixer to be mobile while the community in Nicaragua did. Therefore, it was imperative to make design changes to fit their needs.

12.4 Conclusion

The HPCM provides an alternative to the current method of mixing concrete with shovels for non-profits in remote locations. The machine is low cost, efficient, mobile, and reproducible. The mixer will help non-profit organizations and social enterprises operate more efficiently when doing construction projects in developing countries.

Though there are areas for improvement in the HPCM, testing has proven that the mixer is effective in its current state. The plans for the mixer will be sent to Nicaragua, so that Amigos for Christ can build and use the HPCM on their remote auxiliary construction locations.

References

"Amigos For Christ and Affiliate Consolidated Financial Statements." *AmigosforChrist.org*, Accessed 12 May 2017.

Ari, Alexandru-Radu1, radu.ari@ulbsibiu.ro, and Dan Maniu, danmaniu.duse@ulbsibiu.ro DUSE. "Structure Properties Of A Frame For Human Powered Vehicles." Academic Journal Of Manufacturing Engineering 11.2 (2013): 12-17. Applied Science & Technology Source. Web. 23 Oct. 2016.

Dai, Dan, and Jing Liu. "Human Powered Wireless Charger For Low-Power Mobile Electronic Devices." IEEE Transactions On Consumer Electronics 58.3 (2012): 767-774. Applied Science & Technology Source. Web. 23 Oct. 2016.

Danso, Humphrey. "Influence Of Compacting Rate On The Properties Of Compressed Earth Blocks." Advances In Materials Science & Engineering (2016): 1-8. Applied Science & Technology Source. Web. 7 Oct. 2016.

"Design Of A Practical Human-Powered Contactless Charger For Cellphone." IEEE Transactions On Consumer Electronics 59.3 (2013): 476-482. Applied Science & Technology Source. Web. 23 Oct. 2016.

Dizhur, Dmytro, et al. "Building Typologies And Failure Modes Observed In The 2015 Gorkha (Nepal) Earthquake." Bulletin Of The New Zealand Society For Earthquake Engineering 49.2 (2016): 211-232. Academic Search Complete. Web. 23 Oct. 2016.

Dos Santos, Clarissa Armando, et al. "Building with Earth -- Brazil's Most Popular Raw Earth Building Techniques and the Opinion of Experienced Builders." *Key Engineering Materials* 600. (2014): 123-131. *Applied Science & Technology Source*. Web. 10 Nov. 2016.

Gates Corporation. *Selecting the Right Drive System.* Web, Nov 15 2016. http://www.reliableplant.com/Read/2418/selecting-drive-system

Klimiec, Ewa1, zrklimie@cyf-kr.edu.pl, et al. "Piezoelectric Polymer Films As Power Converters For Human Powered Electronics." Microelectronics Reliability 48.6 (2008): 897-901. Applied Science & Technology Source. Web. 23 Oct. 2016.

"Nepal's Farmers Pedal Bikes to Pump Water and Irrigate Land." *U.S. Agency for International Development*. USAID, 13 Oct. 2015. Web. 02 Dec. 2016.

Riccomini, D. *Ethics Decision Making Tool.* ENGL 181 Fall 2016 Lecture Material.

Robertson, Cameron D., and Todd M. Reichert. "Design and Development of the Atlas Human-powered Helicopter." Journal of the American Helicopter Society 60.1 (2015): n. pag. Engineering Village. Web. 16 Oct. 2016.

Shrestha, Deepanjal, and Seung Ryul Jeong. "An Exploratory Study on the Usage of Internet Technologies and Tools in Educational Working Environment of Developing Countries: A Case of Pokhara University in Nepal." *Journal of Korean Society for Internet Information* 16.4 (2015): 101-110. *Applied Science & Technology Source*. Web. 7 Nov. 2016.

Shrestha, Yadin. "Observed Behavior of Reinforced Concrete and Unreinforced Masonry Buildings in April 25, 2015 Nepal Earthquake." *Journal of the Institute of Engineering* 11.1 (2015): 177-181. *Applied Science & Technology Source*. Web. 10 Nov. 2016.

Sontag, Deborah. "Rebuilding in Haiti Lags after Billions in Post-Quake Aid." *The New York Times*. The New York Times Company, 23 Dec. 2012. Web. 01 Dec. 2016.

Taylor, Alan. "Nepal's Earthquakes: One Year Later." *The Atlantic.* Atlantic Media Company, 25 Apr. 2016. Web. 12 Oct. 2016.

University of Sheffield. "Student uses pedal power to create novel machine." *ScienceDaily*. ScienceDaily, 1 June 2010. Web. 10 Nov. 2016.

Valigi, Maria Cristina1, mariacristina.valigi@unipg.it, Silvia1, silvia.logozzo@unipg.it Logozzo, and Mirko2, mirko.rinchi@unifi.it Rinchi. "Wear Resistance Of Blades In Planetary Concrete Mixers. Part II: 3D Validation Of A New Mixing Blade Design And Efficiency Evaluation." Tribology International 103.(2016): 37-44. Applied Science & Technology Source. Web. 23 Oct. 2016.

Wilson, David Gordon, 1928-. "A Short History Of Human-Powered Vehicles." American Scientist 74.(1986): 350-357. Applied Science & Technology Source. Web. 23 Oct. 2016.

Yan, Chu. "Five Innovative Materials for Sustainable Structural Engineering." *Mechanical Engineering* 138.8 (2016): 14-15. *Applied Science & Technology Source*. Web. 2 Dec. 2016.

Zhemchuzhnikov, Alexandr1, alx.zhm@gmail.com, Khosrow1, ghavamil@puc-rio.br Ghavami, and Michéle1, michele.casagrande@hotmail.com Dal Toé Casagrande. "Static Compaction Of Soils With Varying Clay Content." Key Engineering Materials 668.(2016): 238-246. Applied Science & Technology Source. Web. 7 Oct. 2016.

Appendix A: Product Design Specifications

Table A.1 PDS Chart

Parameter	**Description**	**Datum**	**Units**	**Estimated Value**
Rotational Speed	Minimum speed necessary to effectively mix concrete	25(1)	RPM	20 RPM
Amount of Mixed Material	Amount of material that must be mixed in order to make one batch. Given by Conscious Impact.	0.12(2)	m^3	.12 m^3
Drum Volume/Batch Volume Ratio	Ratio of drum volume to batch volume. The drum must be larger than the batch in order to effectively mix the batch.	1.833(1)	____	2
Volume of Drum	Necessary inner volume of drum. Determined based off batch/drum volume ratio from portable mixer and batch volume given by Scott Hanson.	0.2196(1,2)	m^3	.24 m^3
Weight to be supported by frame	The combined weight of the drum and batch.	70(2)	kg	70 kg
Power necessary to achieve desired RPM	The necessary power output for the drum to rotate at 20 RPM	200(1)	W	200 W
Torque	Torque necessary to produce desired power.	120 (1)	N-m	N-m
Cost	How much it will cost to produce one individual mixer	500-2,000 (1)	$ US	$250
Price	How much target market will have to pay for one individual mixer. Roughly based on a 10% buy-in approach used in similar non-profits.	___	$ US	$25
Drum Opening	Diameter of opening of the drum, which is important for both loading and unloading batches.	0.381 (1)	m	0.4 m
Drum Diameter	Drum diameter at widest point	.6 (1)	m	0.65 m
Drum depth	Length from back of drum to drum opening	0.6 (1)	m	0.65 m
Discharge height	Height from which mixed concrete batches will be poured	0.6 (1)	m	0.6 m
Time per batch	Amount of time required to mix each batch	1 min (portable mixer), up to 10 minutes for hand mixing (1,2)	1 minute	3 minutes

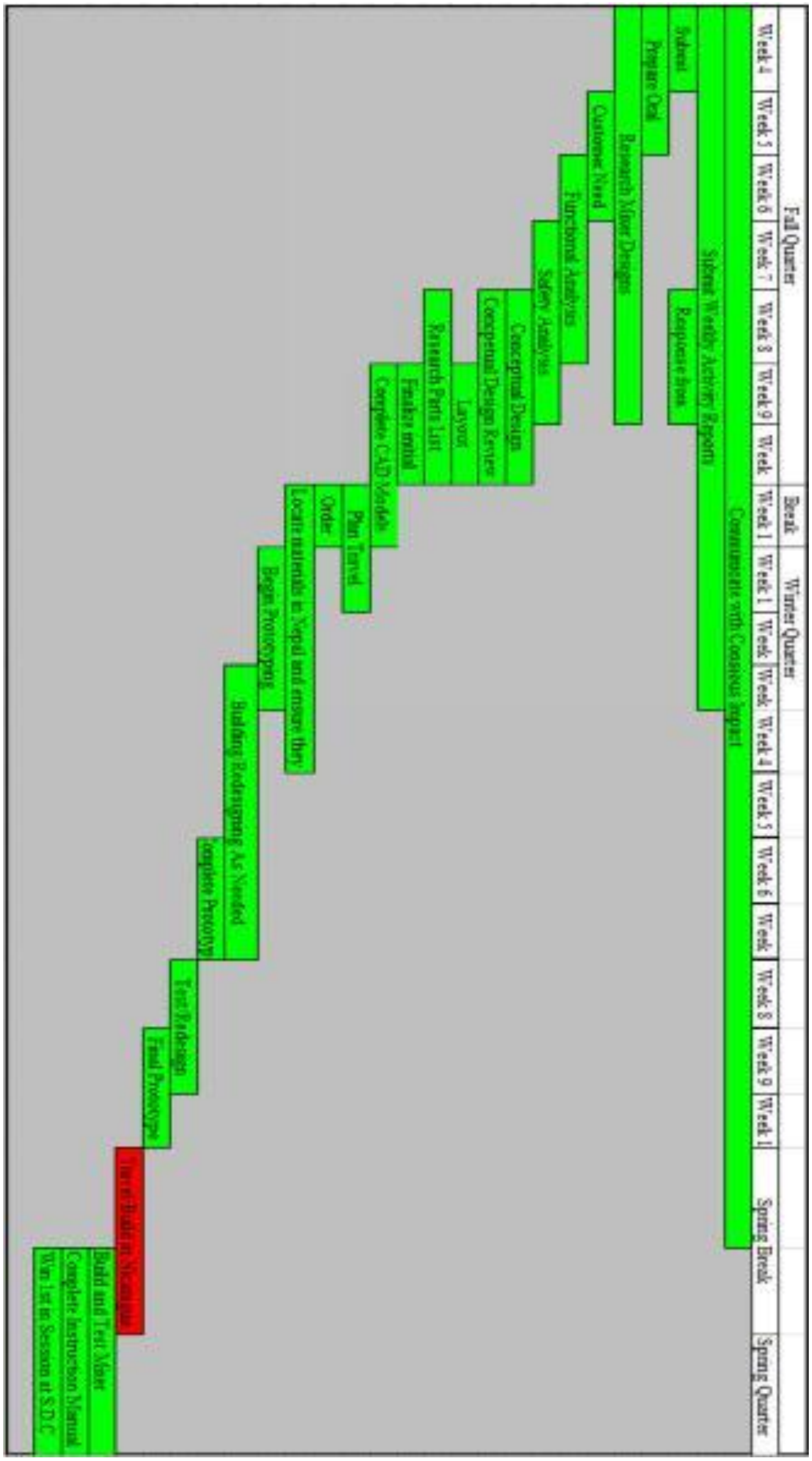
Angle	Angle of tilt of drum required to allow compressed earth mixture to fall out of drum when mixed	-45 degrees from horizontal (1)	degrees	-45 degrees
Life	Amount of time the machine can be used with regular use each day (8 hrs/day, 5 days/week)	5 years (1)	years	5-10 years
Assembly Time	Amount of Time machine will take to assemble in Chinandega	1 day (1)	Week	5 days

Appendix B: Team and Project Management Spreadsheets

Table B.1 **Estimated Cost of Constructing the Mixer**

Human-Powered Mixer Budget			
	Subsystem	Component	Commercial Price (US Dollars)
Supplies	Mixing Chamber	Drum	$300
		Paddles	$100
		Steel Ball Bearings	$50
	Frame	Mixer Stand	$150
		Bearings	$50
		Wheels	$40
	Power Transmission System	Rotation Shaft	$100
		Gears	$200
		Sprockets	$20
		Chain	$30
	Testing Supplies	Cement	$50
		River Silt (or fine sand)	$20
		Soil	$50
Student Wages	Not Applicable		$0
Contracted services	Machining of Specialty Parts		$750
Special events	Not Applicable		$0
Miscellaneous	Shipping of Specialty Parts		$600
	Redesign and Repair		$500
Total			$3,010

Appendix C: Gantt Chart



Appendix D: Design Ideation Sketches

Included in this section are the design sketches created by the team during the brainstorming process. The sketches show ideas for both the final design and the subsystems.

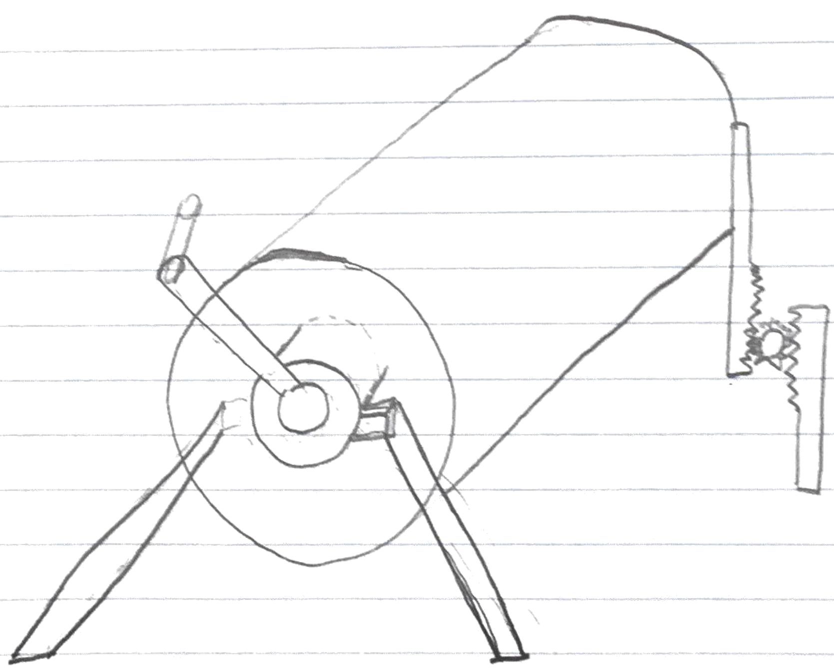
Connor McLoughlin
11/8/16

Sketches of Potential Designs

Subsystems

Power Transmisson	Unloading Mechanism	Human Interface
Gear Train	Hatch	Crank
Chain Drive	Tip	Bike
Belt Drive		Rope

Option 1: Gear Train, Tip, Crank

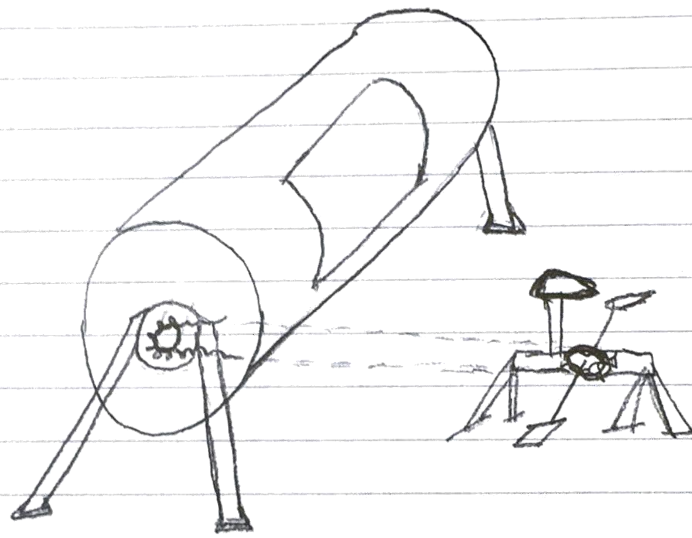


Description: Turned by a hand crank in the front. Gear train makes it turnable by 1 person. Unloaded by tipping the back using the geared back legs.

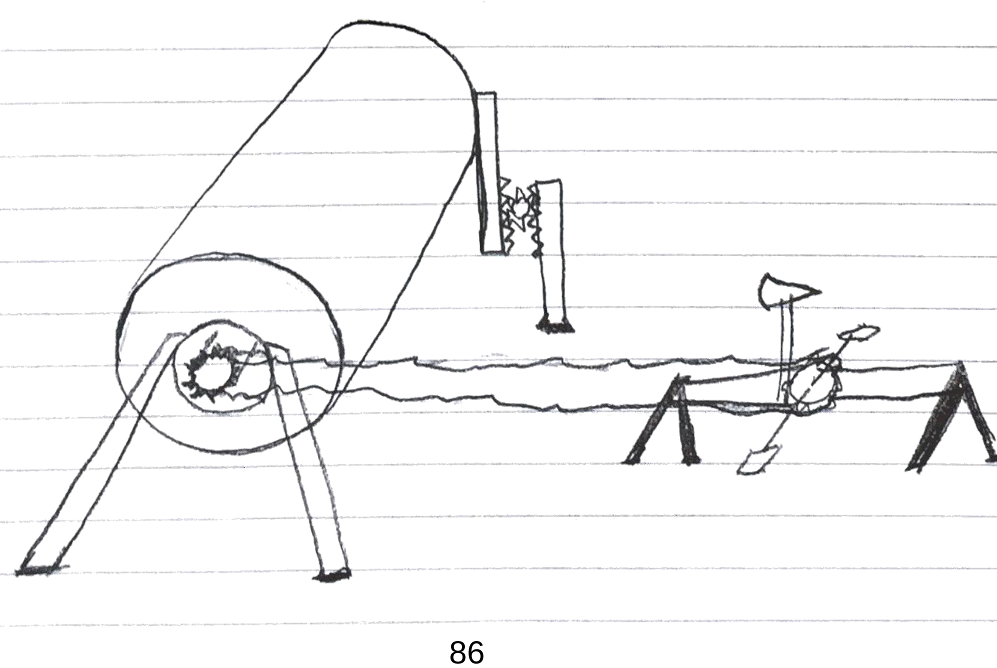
Benefits: Tipping will be more efficient than a hatch

Negatives: Expected mixing time of 2 minutes, users arms will get tired.

Option 2: Chain Drive, Hatch, Bike
Benefits: easy construction
Negatives: Hatch will be less efficient than other unloading methods



Option 3: Chain Drive, tilt, bike
Benefits: More power from bike than from crank
Negatives: More difficult to construct.

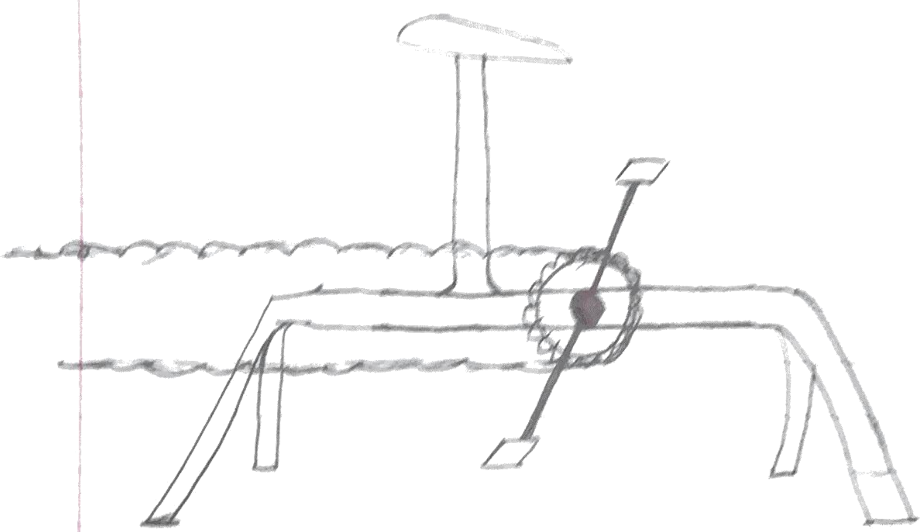


Subsystem Sketches: Human Interface

Human Interface options: Bike, hand crank, rope, pedal

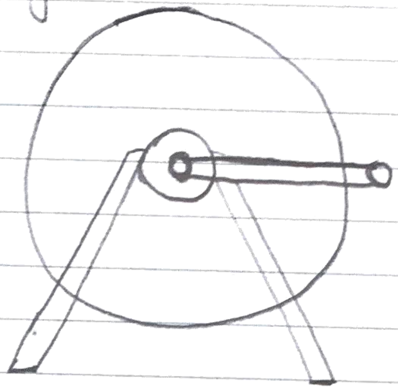
Bike

- Wheels removed, chain connected to mixer
- Benefits: More consistent / Higher power output compared to other options
- Negatives: might be difficult to modify bike in the proper way



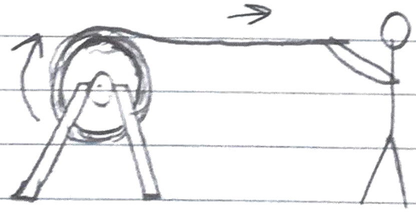
Hand crank

- Handle connected to a gear train to make turning easier
- Benefits: Mixer is all one peice
- Negatives: Tireing for user



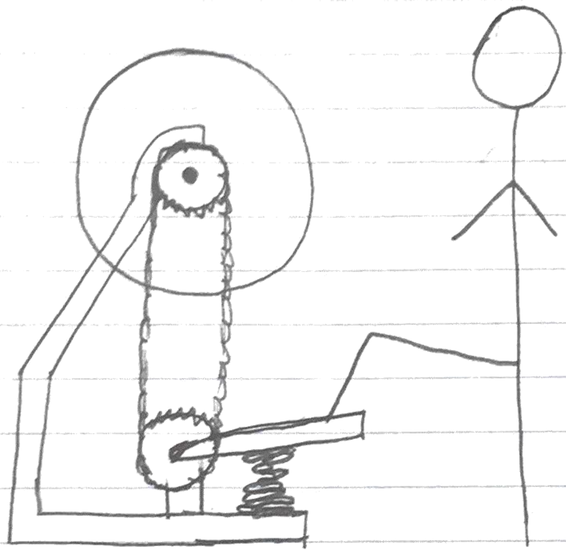
Rope

- Rope wrapped around drum of mixer. Pulling rope spins mixer
- Benefits: Predetermined number of rotations based on rope length
- Negatives: Potentially an inconsistant mixing speed, difficult to re-wind rope



Peddal

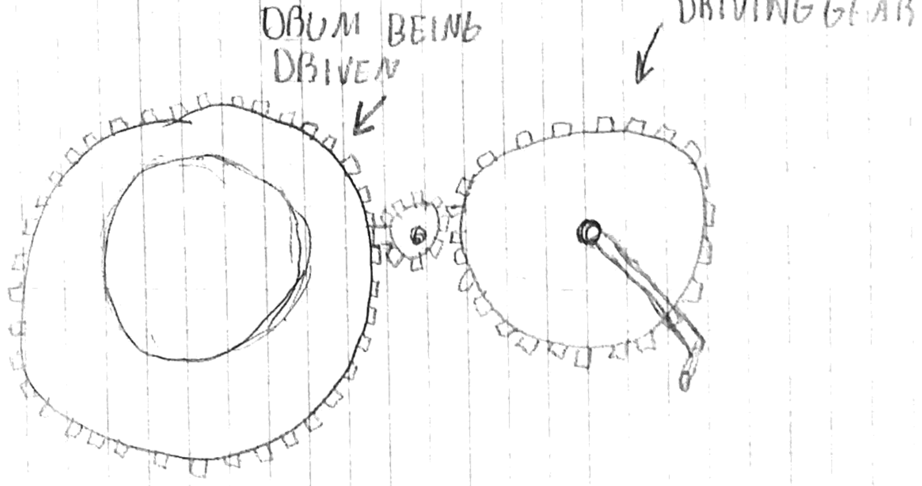
- Spring loaded Peddal, when the peddal is pushed it turns the drum
- Benefits: uses legs and body weight, so easier for the user
- Negatives: Pulsing rotatation, difficult to design



POWER TRANSMISSION SUBSYSTEM

1. GEAR TRAIN

NICK SZYCHOWSKI 11/6/2016



- CRANK TURNS THE DRIVING GEAR
- SMALLER DRIVEN GEAR ALSO TURNS DRUM
- GEAR REDUCTION INCREASES VELOCITY

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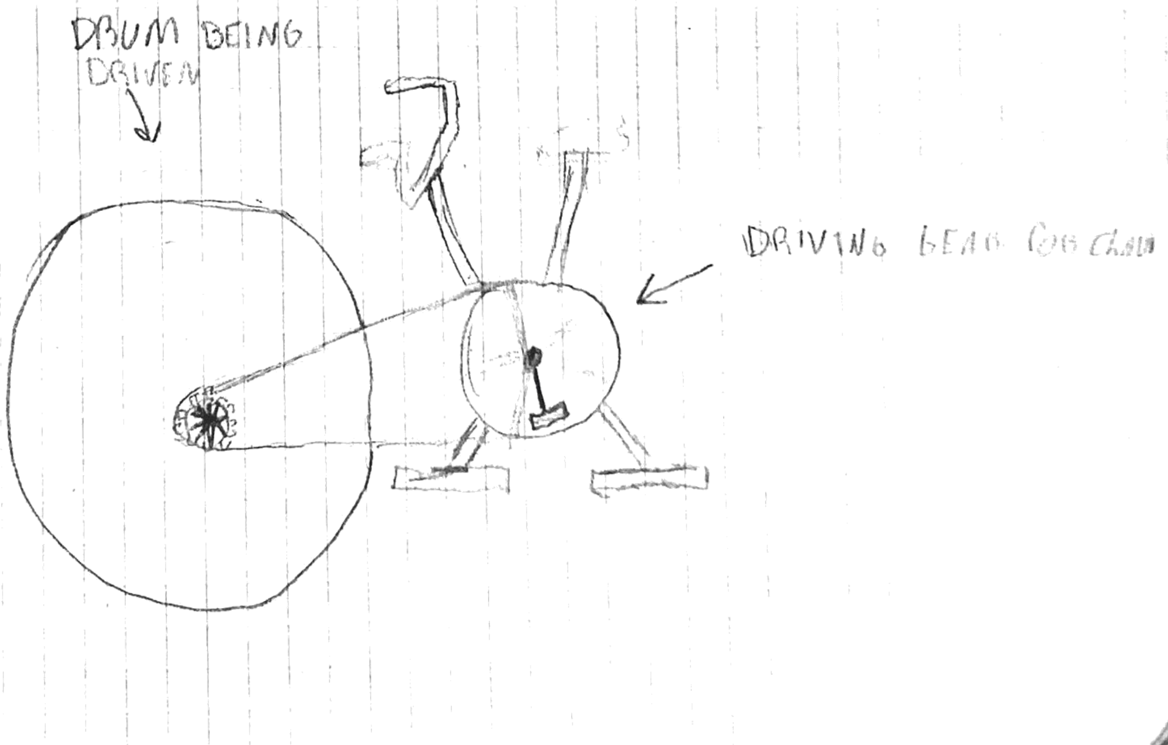
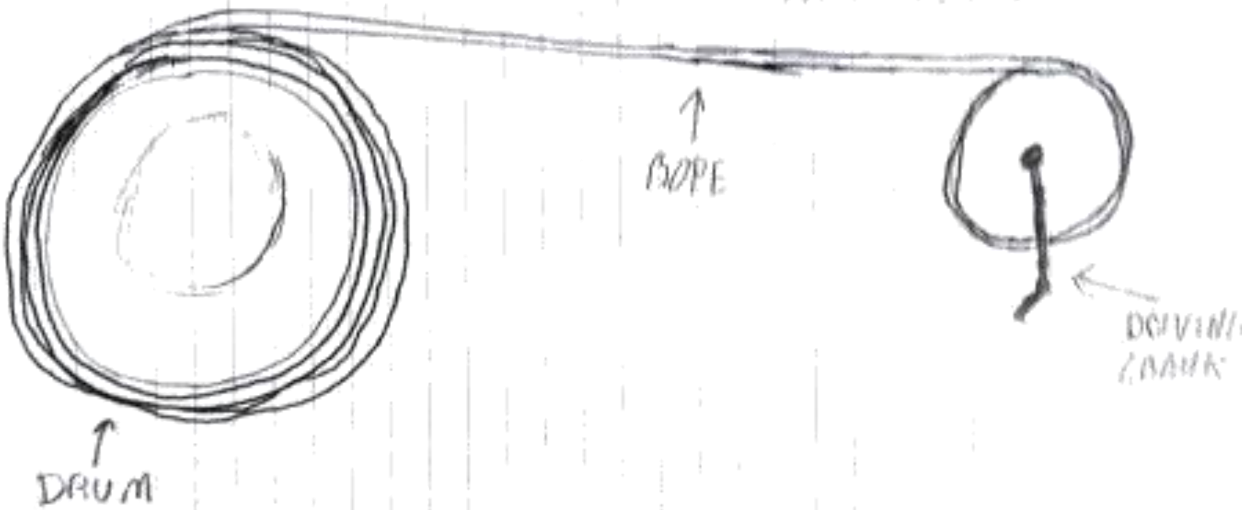
2. CHAIN DRIVE

- VERY SIMILAR TO CHAIN DRIVE ON BICYCLE
- GEAR CONNECTED TO PEDALS DRIVES CHAIN
- CHAIN DRIVES SMALLER GEAR ON AXLE WHICH IS CONNECTED TO DRUM (DRUM ROTATES)



3. ROPE/SPOOL SYSTEM

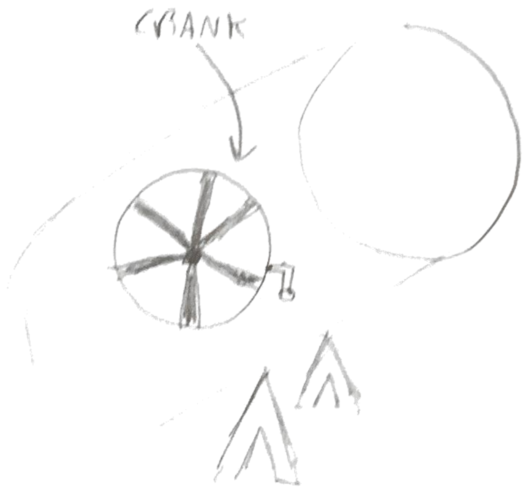
11/6/2016
NICK [illegible]



- THE CRANK TURNS THE WHEEL
- AS THE WHEEL TURNS THE ROPE [illegible] FROM THE DRUM [illegible]
- ROPE IS PRE SET TO DESIRED LENGTH, MIXTURE IS DONE [illegible]
- ESSENTIALLY AN ENORMOUS SPOOL OF THREAD [illegible]
- CRANK ON DRUM WILL REWIND AND SPOOL UP ROPE AFTER COMPLETION

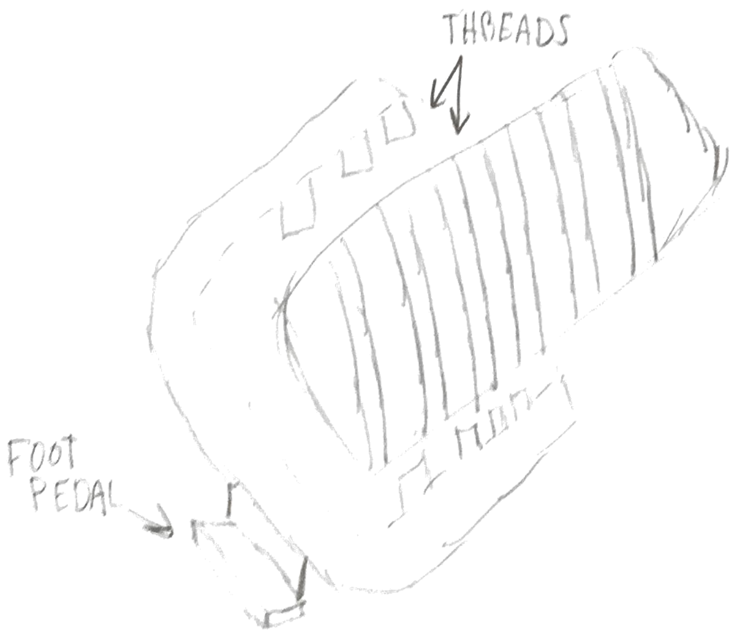
1. COMPRESSED EARTH MIXER DESIGNS

- CRANK/WHEEL IS HAND OPERATED
- CRANK ROTATES THE GEARS IN A GEAR TRAIN WHICH ROTATES THE DRUM



- HUMAN INTERFACE IS THE WHEEL, SIMPLY ROTATING WHEEL TURNS IT

2. THREADED DRUM SYSTEM:
- THE ENTIRE DRUM IS THREADED ON THE OUTSIDE
- MUST BE WELL LUBRICATED/HAVE BEARINGS
- THREADS WILL BE ANGLED TO ALLOW EASY TURNING

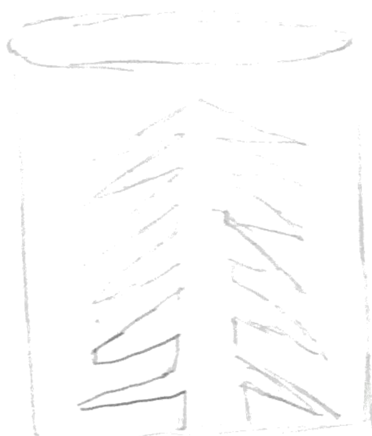


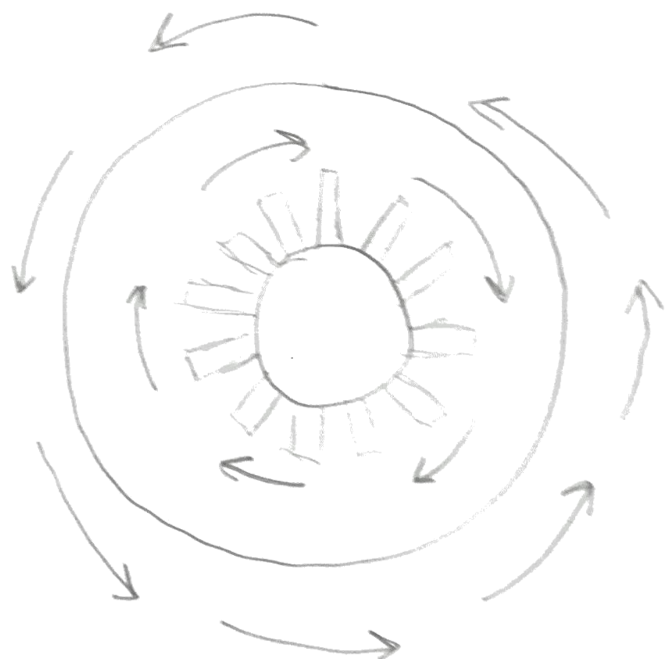
→ MANY SMALLER DEVICES WITH SIMILAR DESIGN INSPIRED THIS IDEA

NICK SZYCHOWSKI
10/20/2016

3. REPLACEABLE PARTS FOR DRY WISK AND WET SPATULA:

- SIMILAR TO AN EGG BEATER
- OUTSIDE WALL AND INTERIOR WILL SPIN IN ALTERNATE DIRECTIONS
- WISK FOR DRY MATERIAL CAN BE USED
- THICKER SPATULA BLADES CAN REPLACE THEM WHEN WATER IS ADDED
- WILL MIX QUICKLY WITH ALTERNATING ROTATIONAL DIRECTIONS



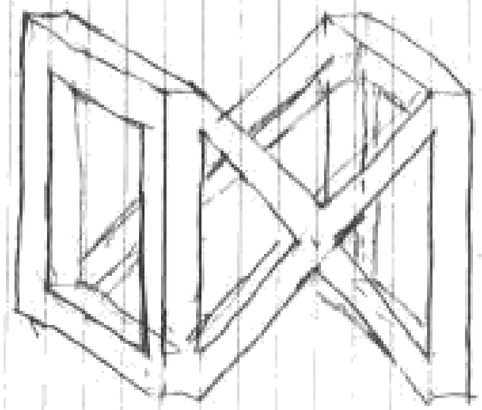


NICK SZYCHOWSKI

10/20/2016

1/7

- Metal frame using less material than wood frame design
- stronger material fewer pts of contact



Iron

Pros
- easy to find in [illegible]
- heavy
  good counterweight

Cons
- hard to work with
- prone to rust

Aluminum

Pros
- won't rust

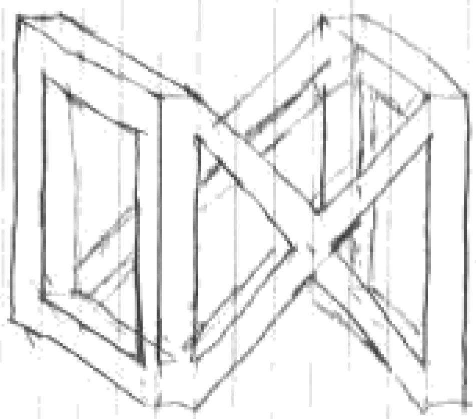
Cons
- lightweight
- maybe harder to find

- Bicycle adapted into stationary bike for power
- Bike may be found

11/1

Metal frame using less material than wood frame design

Stronger material fewer pts of contact



Iron

Pros
- easy to find & cut
- heavy
  good counterweight

Cons
hard to work with
- prone to rust

- Bicycle adapted into stationary bike for power
- Bike may be found

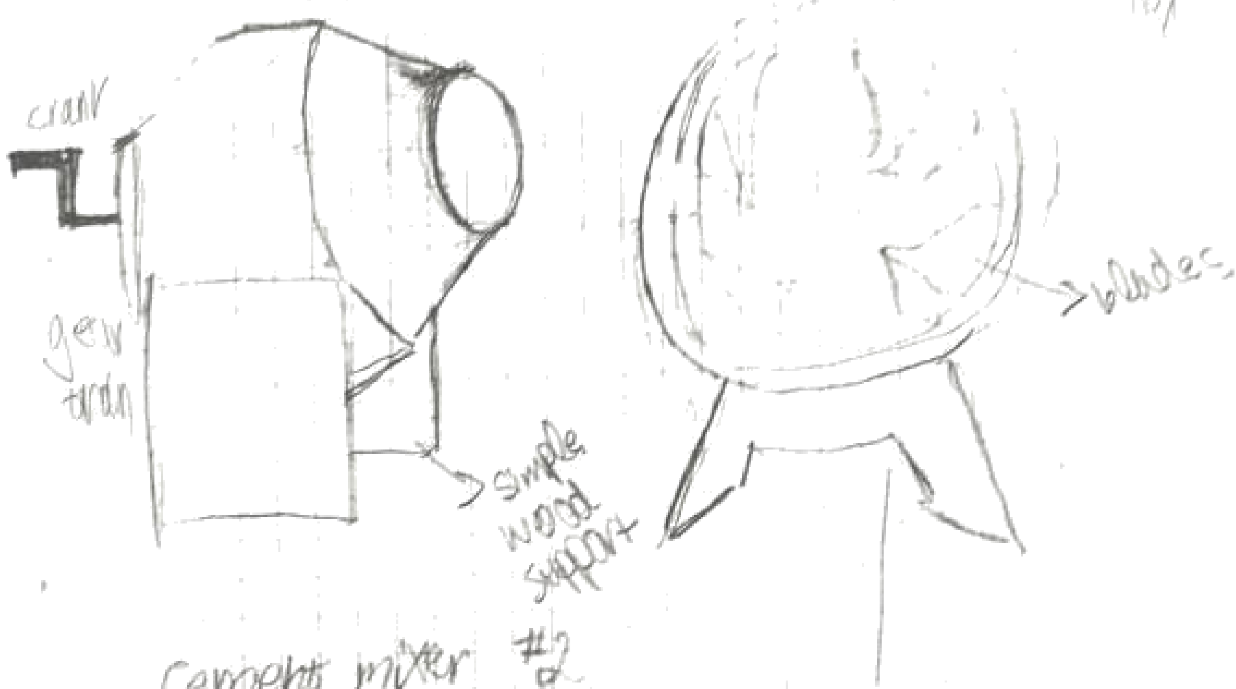
Aluminum

Pros
- won't rust

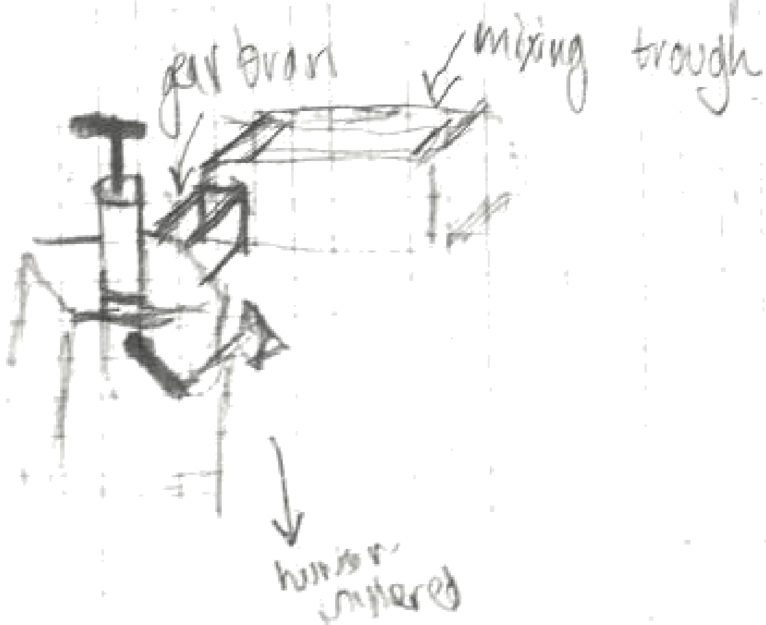
Cons
lightweight
- maybe harder to find

10/26/16 Prelim Design #1

Cement mixer #1



Cement mixer #2



11/4/16

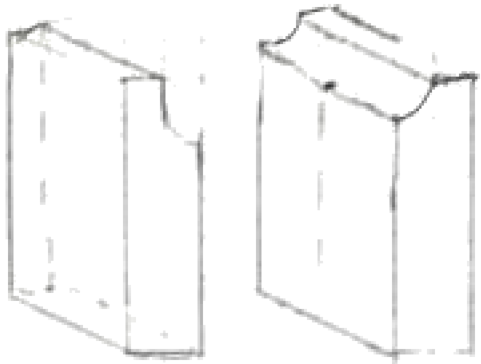
compressed mixer #3

Madelyn Broeker-Isaacson

Frames 11/7/16

Preliminary Sketches

simple block supports for barrel



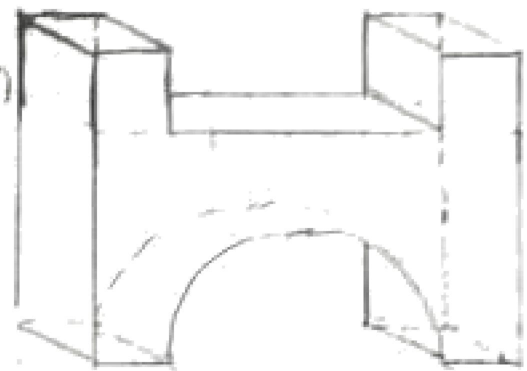
-wood design

Pros

-wood easy to find

-sustainable

Bridge design



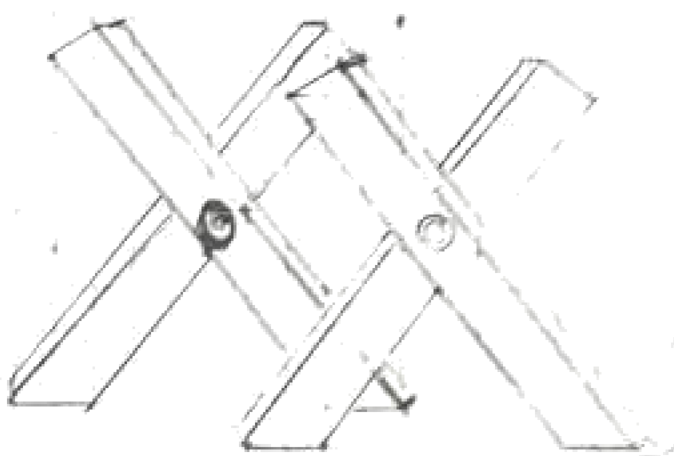
- many designs

-easy to machine

-heavy

Cons

-suspect to rot



X-Frame wood design

Appendix F: Preliminary Calculations

The following calculations are included

- Weight of the drum when it is containing the mix
- Height of mix in drum before falling at a given RPM with no paddles
- Wight to be lifted by mixing blades
- Impact energy of mix on bottom of drum during mixing
- Height of mix in drum when at rest
- Moment of inertia of loaded drum
- Torque to turn drum
- Power to maintain rotation
- Necessary gear ratio

Total Mass of Loaded Drum

Mass of Drum: 43 lb = 19.5 kg

Density of Mix Materials

$\rho_{soil} = 1922\ kg/m^3$

$\rho_{sand} = 1300\ kg/m^3$

$\rho_{cement} = 1201\ kg/m^3$

$\rho_{water} = 1000\ kg/m^3$

Volume of Materials

4.5 buckets soil = 22.5 gal = $0.085\ m^3$

1 bucket sand = 5 gal = $0.019\ m^3$

½ bucket cement = 2.5 gal = $0.0095\ m^3$

5 Liters water = 1.3 gal = $0.0049\ m^3$

Total volume = $0.1184\ m^3$

Ratios of Materials

Soil: $\frac{0.085}{0.1184} = 0.718$

Sand: $\frac{0.019}{0.1184} = 0.160$

Cement: $\frac{0.0095}{0.1184} = 0.080$

Water: $\frac{0.0049}{0.1184} = 0.042$

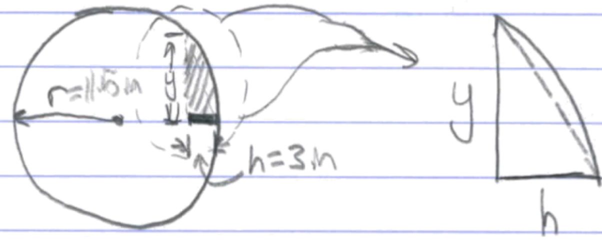
Density of Mix: $\rho_{mix} = [(0.718)(1922) + (0.160)(1300) + (0.080)(1201) + (.042)(1000)]$

$\rho_{mix} = 1725.8\ kg/m^3$

Mass of Mix $= (1725.8\ kg/m^3)(0.08\ m^3) = 138.1\ kg$

Mass of Loaded Drum: $M = 19.5 + 138.1 = \boxed{157.6\ kg}$

Mass to be Lifted by Mixing Blades



• estimate area as a triangle

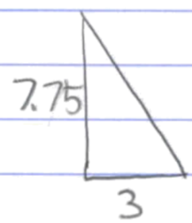
Circle

$11.5 = \sqrt{x^2+y^2}$, $x = r-h = 8.5$ in

$132.25 = x^2+y^2$

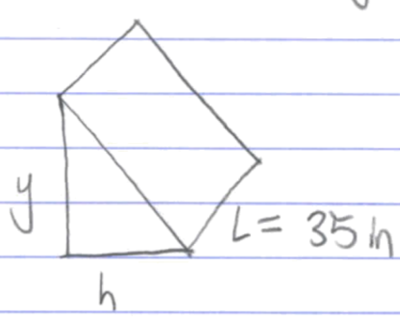
$132.25 = (8.5)^2 + y^2$

$y = 7.75$ in



$\text{Area} = \frac{1}{2}(7.75)(3) = 11.625 \text{ in}^2$

Volume of Mix Being Lifted



$V = (11.625 \text{ in}^2)(35 \text{ in})$

$V = 406.875 \text{ in}^3$

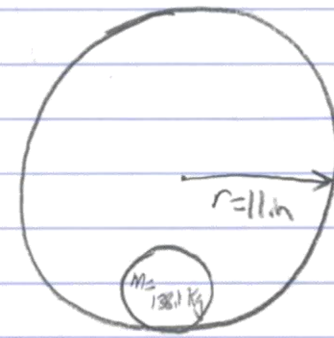
$V = 0.007 \text{ m}^3$

Mass Being Lifted

$M = (0.007 \text{ m}^3)(1725.8 \text{ kg/m}^3) = \boxed{12.1 \text{ kg}}$

Max Impact Energy of Mix on bottom of Drum

State 1 **State 2**



- Mix modeled by a cylinder with the same mass, at the highest point of the mixer
- Mix at bottom of Mixer the instant before impact

State 1

$$KE_i = \frac{1}{2} m v^2 = \left(\frac{1}{2}\right)\left[(138.1\ Kg)\right]\left[(30\ RPM)\left(\frac{1\ \cancel{min}}{60\ Sec}\right)\left(\frac{2\pi(11)\ in}{rotation}\right)\left(\frac{1\ m}{39.37\ in}\right)\right]^2$$

$$KE_1 = \left(\frac{1}{2}\right)(138.1\ Kg)(0.88\ m/s)^2 = 53.2\ J$$

$$PE_i = mgh = (138.1\ Kg)(9.8\ m/s^2)\left[(22\ in)\left(\frac{1\ m}{39.37\ in}\right)\right]$$

$$PE_i = 756.3\ J$$

$$KE_{Final} = 756.3 + 53.2 = 809.5\ J$$

Velocity of Mix Before Impact

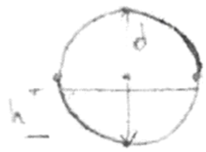
$$KE_{Final} = 809.5\ J = \left(\frac{1}{2}\right)(138.1)\ v^2$$

$$\vec{V} = 11.73\ m/s$$

• SUBSYSTEM: POWER TRANSMISSION • Power Necessary to Rotate Drum.

A) ROTATIONAL P = $T\omega$, where T = torque & ω = angular velocity.

→ $T = I\alpha$ where I = moment of inertia & α = angular acceleration



CALCULATE HEIGHT OF MIX AT REST IN DRUM

d = 572 mm

h = 851 mm

$$V_{drum} = \frac{\pi (d^2)}{4} \cdot h = \frac{\pi (.572\ m)^2}{4} \cdot .851\ m = 0.2187\ m^3$$

→ inputting 0.08 m³ of mix (from current mixing method datum)

→ $\frac{0.08\ m^3}{0.2187\ m^3} = 0.3658$ ← fraction of volume used.

• cross sectional area of drum = $\frac{\pi d^2}{4} = \frac{\pi (.572\ m)^2}{4} = 0.257\ m^2$

→ area taken up by mix = $(0.3658)(0.257\ m^2) = 0.092\ m^2$

→ using this and geometrical relationships, the following dimensions are determined:

r_c

= 0.1568 =

location of centroid.

h = 0.2267 m $\alpha = 77°$

a = 0.06433 m

r = h + a = .286 m

w = 0.55734 m

CALCULATE MOMENT OF INERTIA

mass of drum = 24.5 kg, thickness of wall = 1.5 mm.

$$I_z = \frac{m}{2}(r_1^2 + r_2^2) = m r_2^2 \left(1 - t + \frac{t^2}{2}\right) \quad ; \quad t = \frac{(r_2 - r_1)}{r_2} = \frac{.0015}{0.286} = 0.00524$$

$$\therefore I_z = (24.5\ kg)(0.286)^2 \left(1 - 0.00524 + \frac{0.00524^2}{2}\right)$$

$$= 1.9935\ Kg\text{-}m^2$$

Centroid circular segment = $\frac{4r \sin^3\alpha}{3(2\alpha - \sin(2\alpha))}$; $\alpha = 77° = 1.3439$ radians = 0.1568 m

↳ in x

By parallel axis theorem, (m of mix ≈ 120 Kg)

$$I_{total} = 1.9935\ kg\text{-}m^2 + mr^2 = 1.9935\ kg\text{-}m^2 + (120\ kg)(0.1568\ m)^2 = 4.9438\ kg\text{-}m^2$$

CALCULATE TORQUE

$$T = I\alpha \quad ; \quad \alpha = \frac{\Delta\omega}{\Delta t} = \frac{30\ RPM - 0\ RPM}{1\ s} = 3.14\ rad/s^2$$

$$T = (4.9438\ Kg\text{-}m^2)(3.14\ rad/s^2) = 15.539\ N\text{-}m$$

CALCULATE POWER

$$P = T\omega = (15.539\ Nm)(3.14\ rad/s) = \boxed{48.79\ W}$$

→ not accounting for friction forces/efficiency losses.

CALCULATED BY: N. M.

POWER TRANSMISSION	POWER PROVIDED BY	HUMAN

→ FROM POWER CALCS, NEED ~ 50 W TO ROTATE DRUM

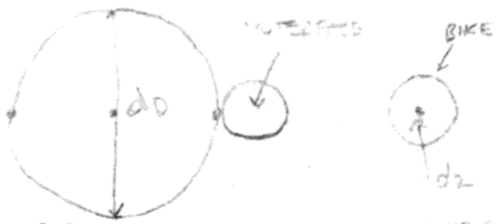
→ EFFICIENCY OF ~90% for CHAIN DRIVE → $(.9)(x) = 50\,W$
→ $x = 56\,W$

→ ACCOUNTING FOR FRICTION, UPPER LIMIT OF EXPECTED POWER OUTPUT IS $\boxed{100\,W}$

CALCULATED BY:

POWER TRANSMISSION: GEAR TRAIN/GEAR RATIO

typical length of 1 chain link: $\frac{1}{2}'' = 0.0127\,m$



NEED USER TO PRODUCE 82 RPM ON BIKE.

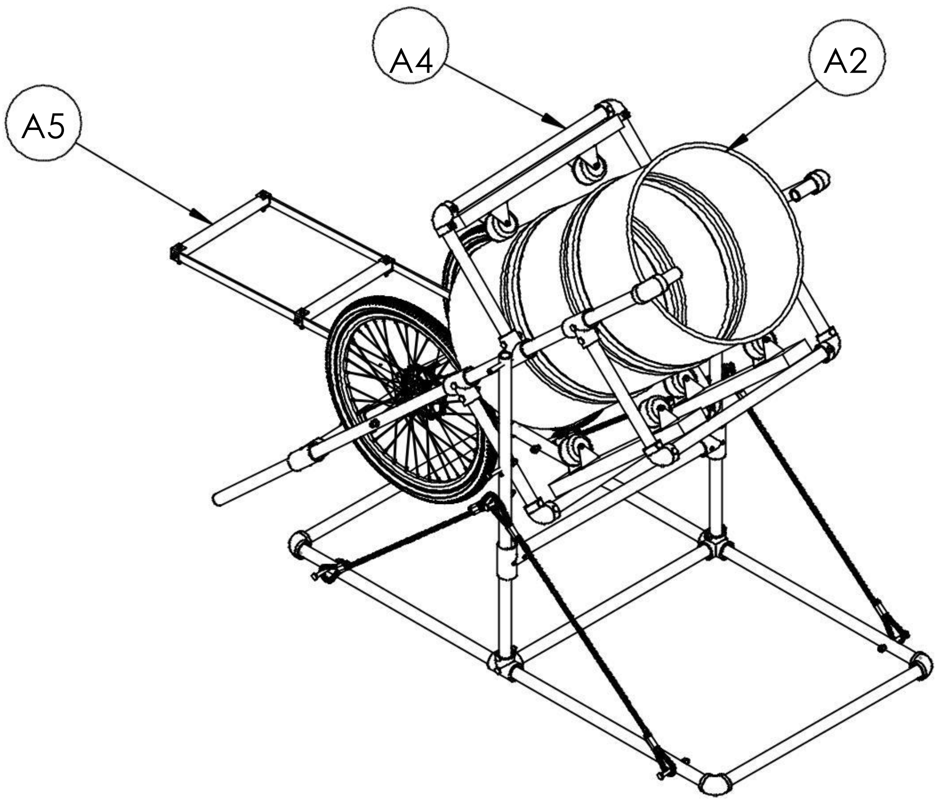
DRUM	INTERFACE	BIKE
N = 30 RPM	N = 213 RPM	$\boxed{N = 82\text{ RPM}}$
D = .572 m		
$C = \pi D = 1.797\,m$		
T = 142 teeth	T = 20 TEETH	T = 52 TEETH

$$N_i = \frac{T_D}{T_I}(N_D) = \frac{142}{20}(30) = 213\text{ RPM} \qquad N_B = \frac{T_I}{T_B} = \frac{20}{52}(213) = 82\text{ RPM}$$

$$\rightarrow P = \tau\omega \rightarrow \underset{\text{from previous}}{100\,W} = \tau(8.59) \Rightarrow \underline{\tau = 11.64\text{ N-m}}$$

→ for perspective, professional cyclists can produce ~50 N-m (350 W)
→ ∴ DESIGN IS FEASIBLE FOR HUMAN-POWER GENERATION OVER A DAY.

CALCULATED BY:



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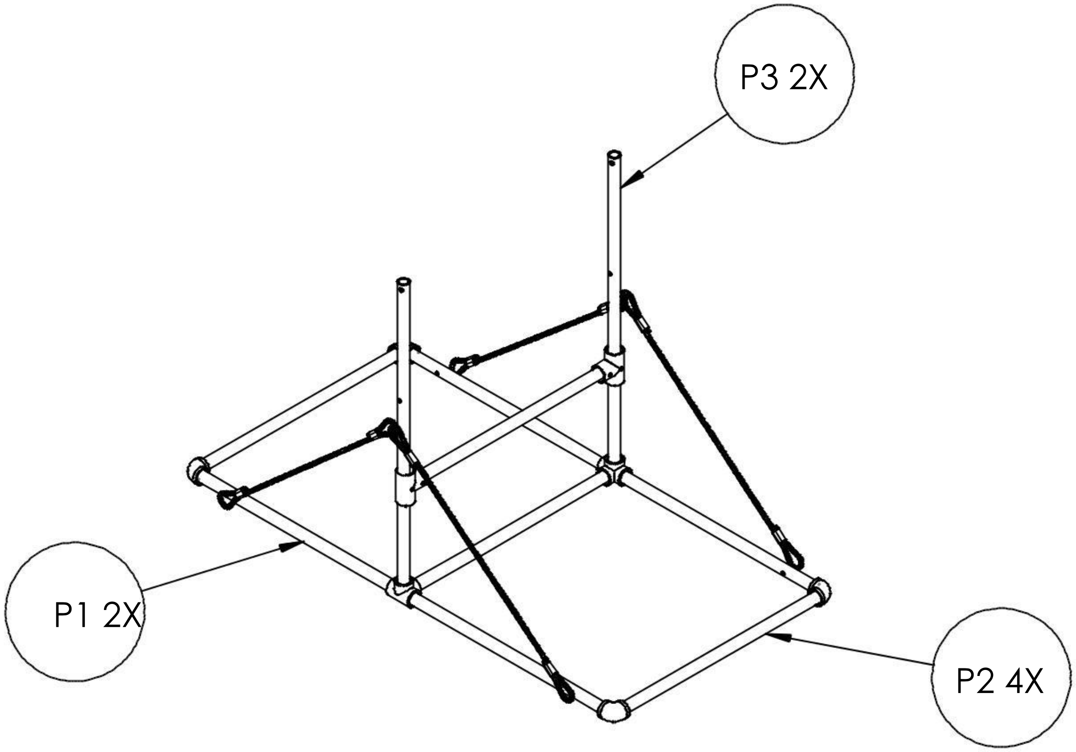
		NA	DRAWN	NS	3/21/2017	TITLE:
			CHECKED			FULL ASSEMBLY
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL NA	COMMENTS:			SIZE A · DWG. NO. A1 · REV
NEXT ASSY	USED ON	FINISH NA				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:50 · SHEET 1 OF 20

2 1

B B



A A

UNLESS OTHERWISE SPECIFIED:

NA

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL NA

FINISH NA

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	NS	3/21/2017
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

HUMAN-POWERED MIXER

TITLE:

LOWER FRAME

SIZE DWG. NO. REV

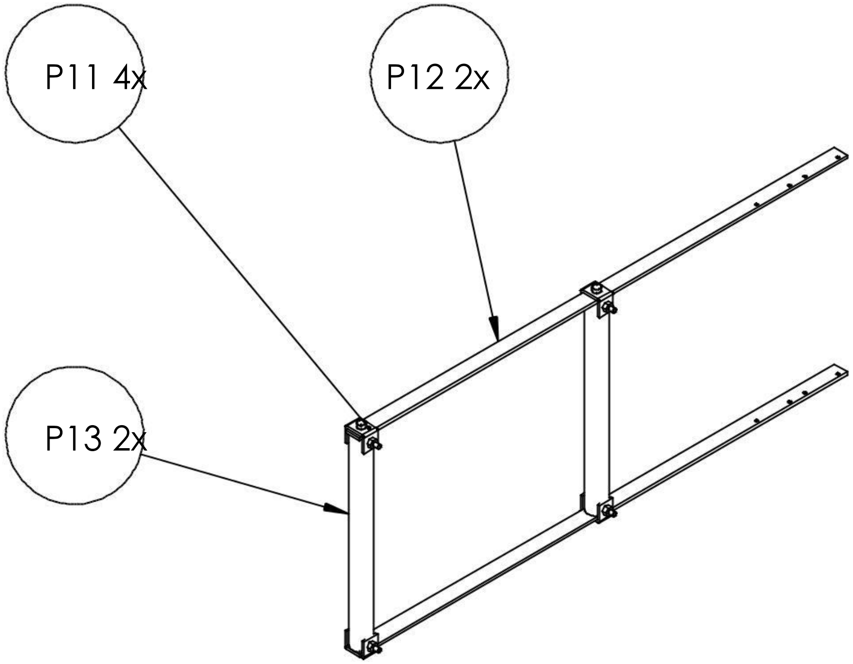
A A3

SCALE: 1:50 SHEET 3 OF 20

NEXT ASSY USED ON

APPLICATION

2 1



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	DRAWN	CM	3/21/2017	TITLE: Power Transmission Assembly Drawing	
	CHECKED				
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL NA	COMMENTS:			SIZE A	DWG. NO. A5
FINISH NA				REV	
DO NOT SCALE DRAWING				SCALE: 1:10	SHEET 5 OF 20

NEXT ASSY	USED ON
APPLICATION	

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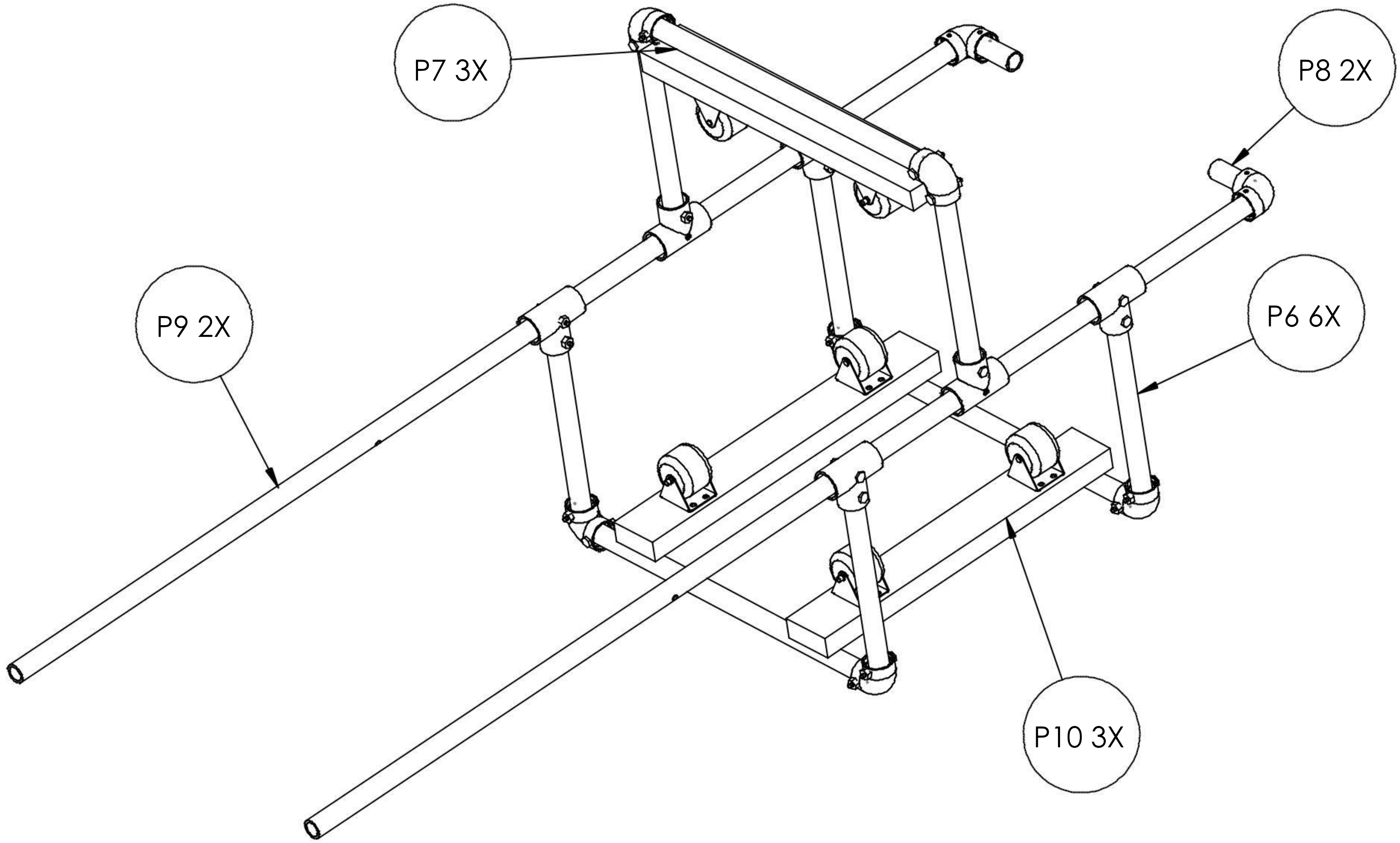
2 1

B B



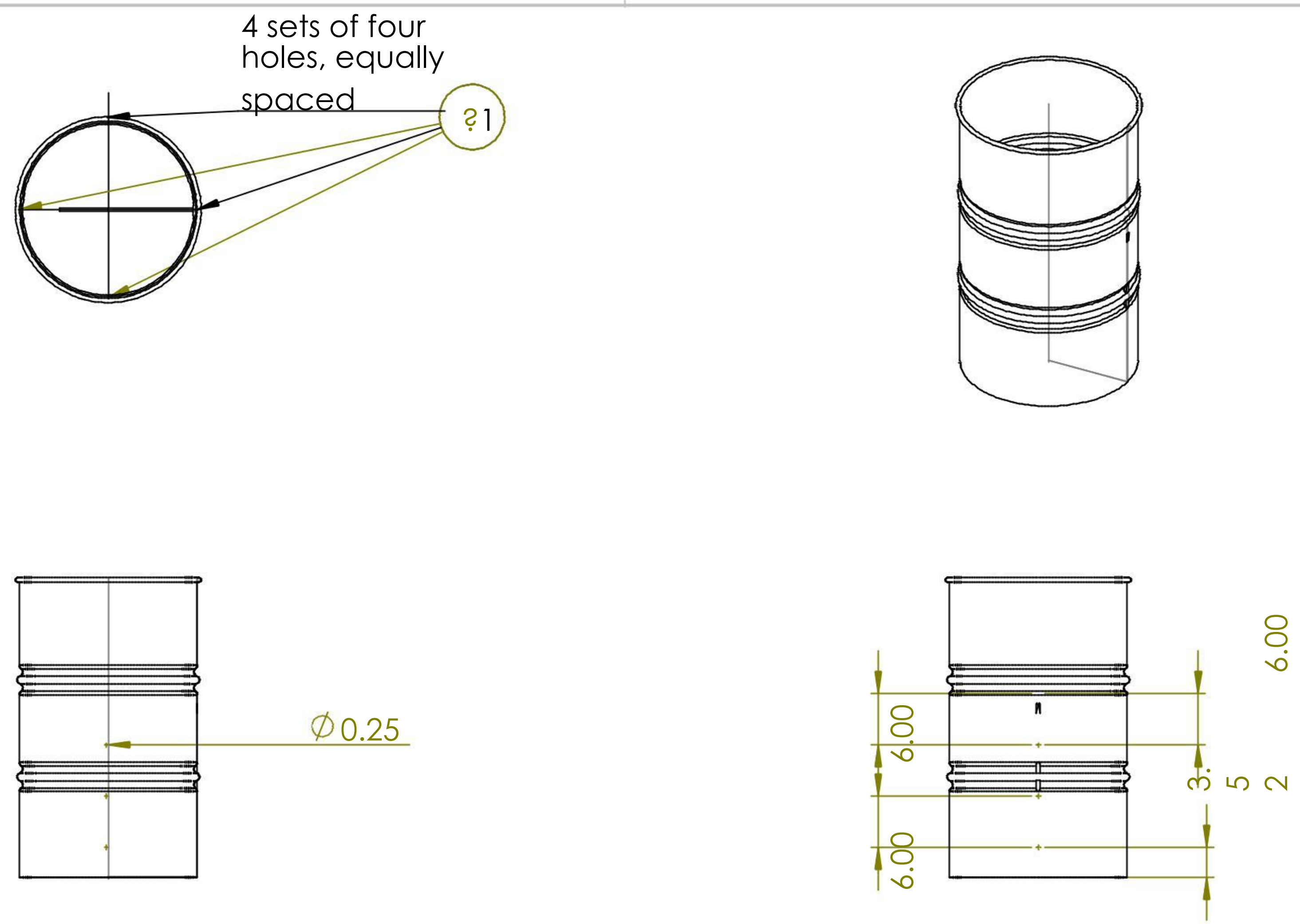
A A

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	HUMAN-POWERED MIXER
		NA	DRAWN	NS	3/21/2017	TITLE:
			CHECKED			UPPER FRAME
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL NA	COMMENTS:			SIZE A DWG. NO. A4 REV
NEXT ASSY	USED ON	FINISH NA				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:50 SHEET 4 OF 20

2 1

2 1

B B



A A

		UNLESS OTHERWISE SPECIFIED:
		DIMENSIONS ARE IN INCHES
		TOLERANCES: 1/8"
		INTERPRET GEOMETRIC TOLERANCING PER:
		MATERIAL
NEXT ASSY	USED ON	FINISH
APPLICATION		DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MBG	3/22/17
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

Human-Powered Concrete Mixer

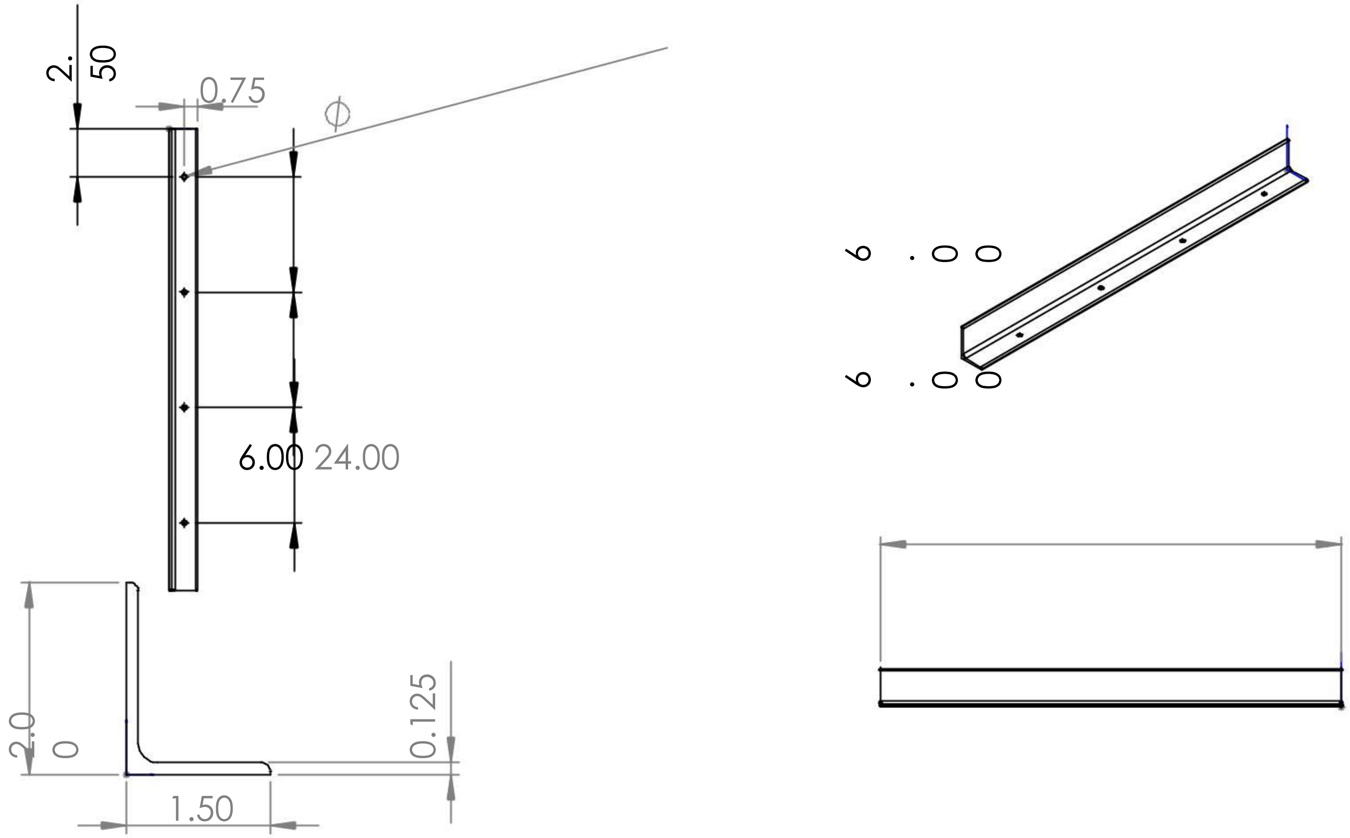
TITLE:

Drum

SIZE	DWG. NO.	REV
A	P15	

SCALE: 1:20 WEIGHT: SHEET 20 OF 20

2 1



Note: Scale 1:2 for cross-section view only

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN IN	DRAWN	NM	3/22/2017
TOLERANCES: 1/8IN	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL ANGLE IRON	COMMENTS:		
FINISH NA			
DO NOT SCALE DRAWING			

NEXT ASSY	USED ON
APPLICATION	

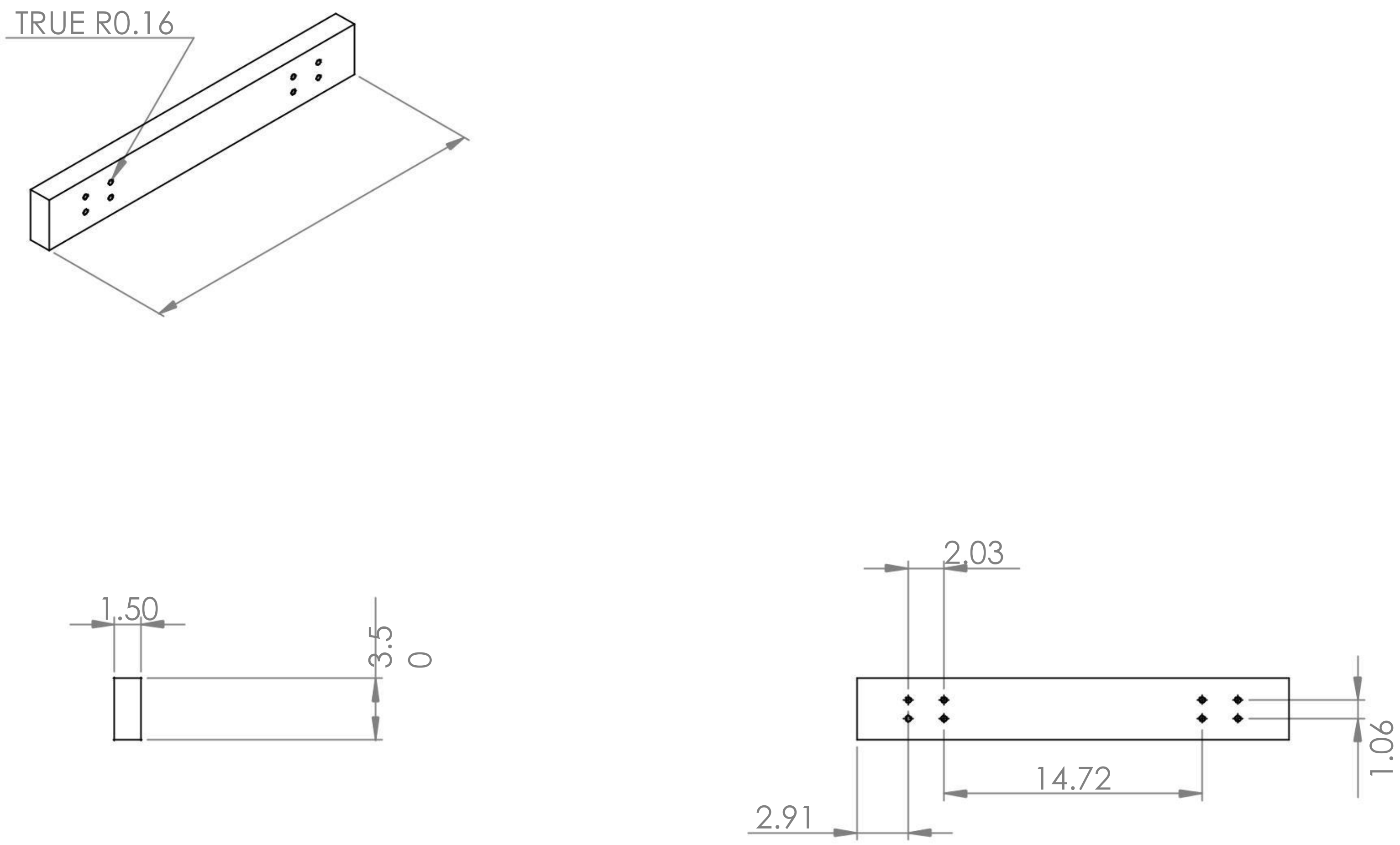
HUMAN-POWERED MIXER

TITLE:

Drum Paddles

SIZE A | DWG. NO. D-002 | REV

SCALE: 1:10 | SHEET 14 OF 20



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APPLICATION	

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DIMENSIONS ARE IN INCHES
TOLERANCES: 1/8

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MBG	3/21/17
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

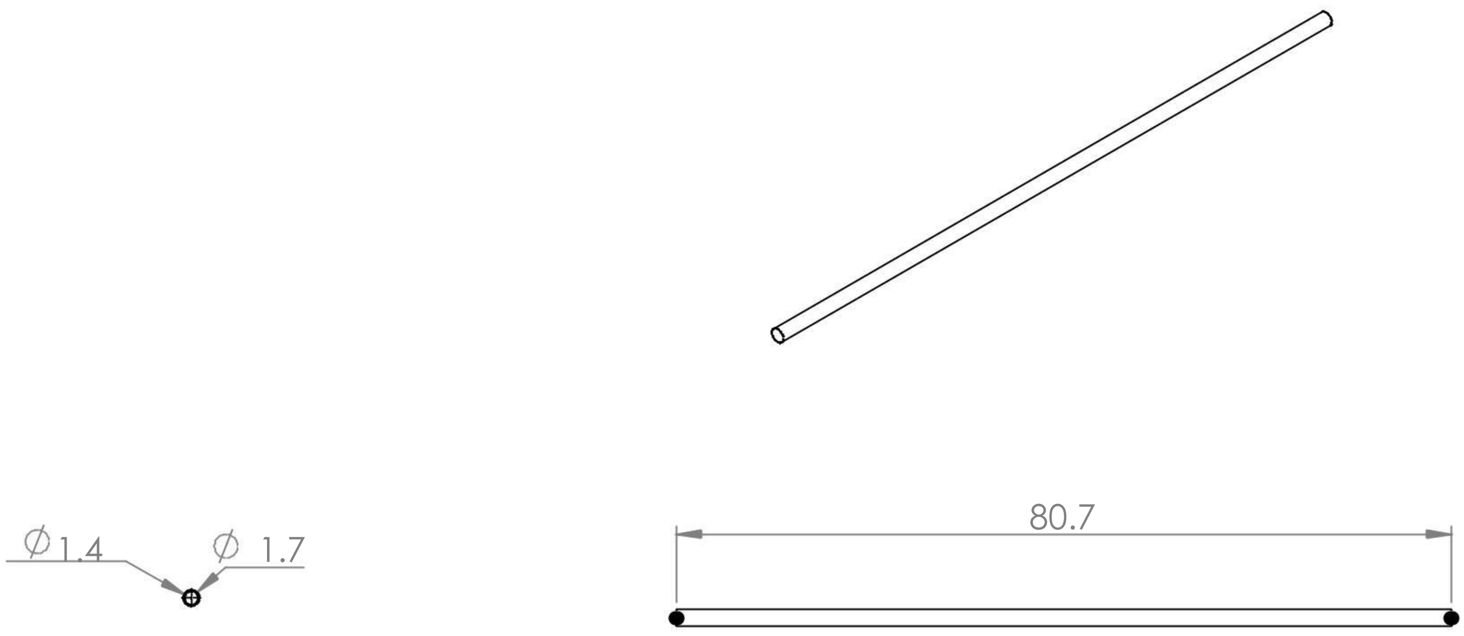
Human-Powered Concrete Mixer

TITLE:

U-Bar Wheel Connection

SIZE **A** DWG. NO. P15 REV

SCALE: 1:10 WEIGHT: SHEET 10 OF 20



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DIMENSIONS ARE IN IN	DRAWN	NS	3/21/2017
TOLERANCES: 1/8IN	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL STEEL TUBE	COMMENTS:		
FINISH NA			
DO NOT SCALE DRAWING			

NEXT ASSY | USED ON

APPLICATION

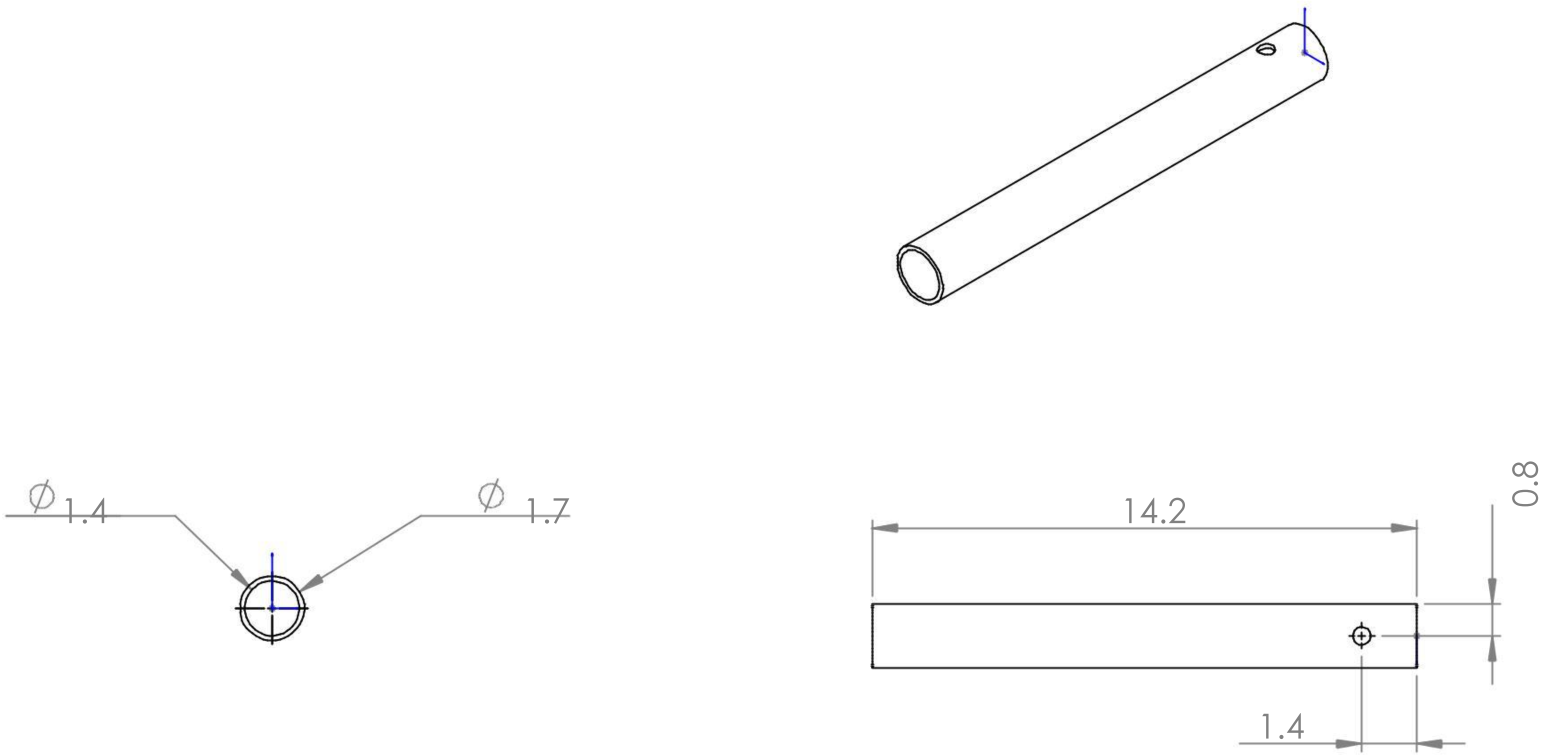
HUMAN-POWERED MIXER

TITLE:

81N LONG HANDLE
(U-FRAME)

SIZE A | DWG. NO. P9 | REV

SCALE: 1:20 | SHEET 14 OF 20



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN IN

TOLERANCES: 1/8IN

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
STEEL TUBE

FINISH
NA

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	NS	3/21/2017
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

HUMAN-POWERED MIXER

TITLE:

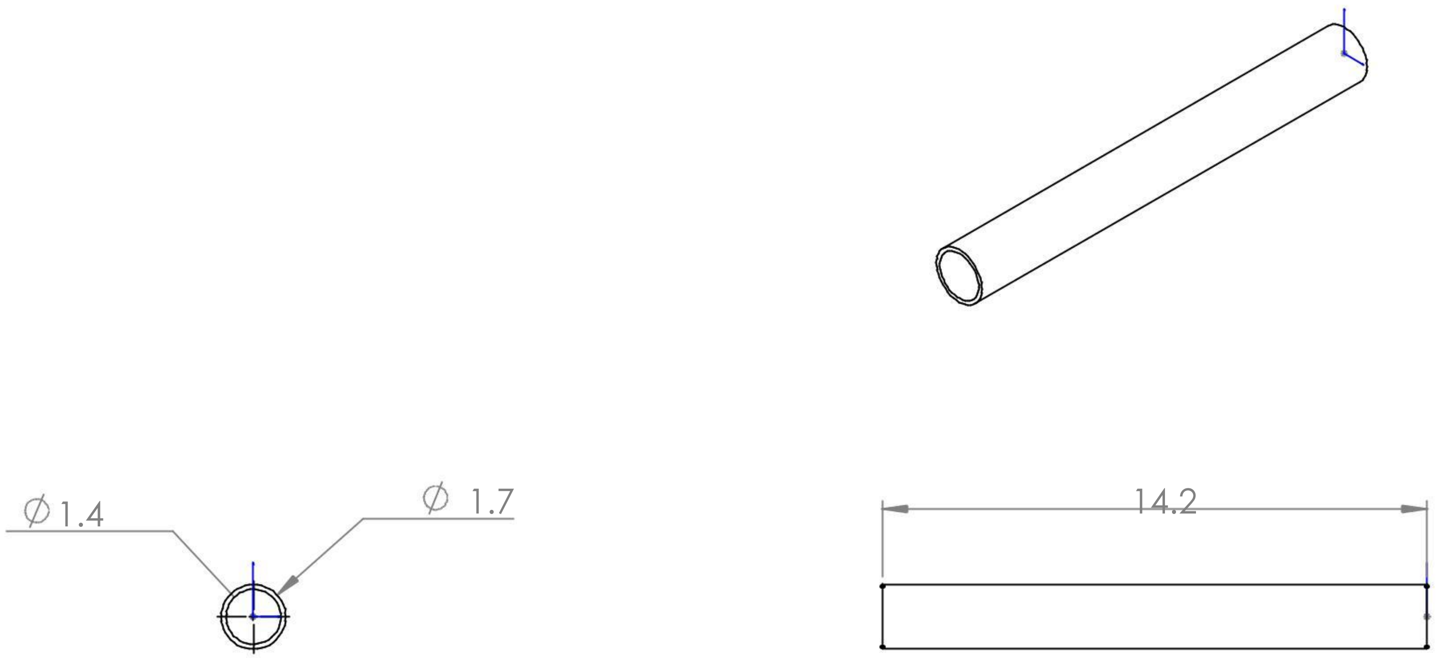
14IN WHEEL SUPPORT

SIZE **A** DWG. NO. P4 REV

SCALE: 1:5 SHEET 9 OF 20

NEXT ASSY USED ON

APPLICATION

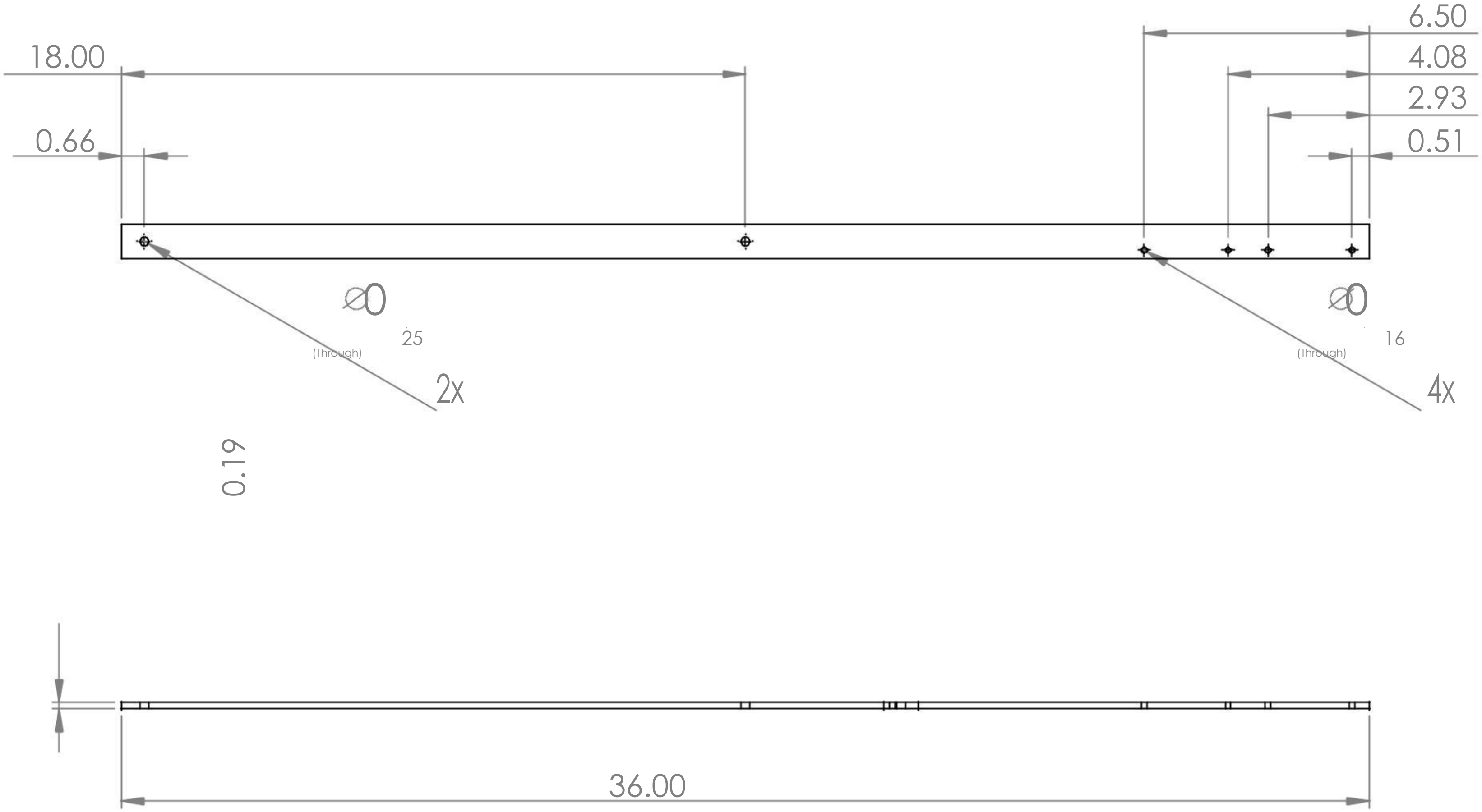


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	HUMAN-POWERED MIXER
DIMENSIONS ARE IN IN	DRAWN	NS	3/21/2017	
TOLERANCES: 1/8IN	CHECKED			TITLE:
	ENG APPR.			14IN VERTICAL PIECE (U-FRAME)
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL STEEL TUBE	COMMENTS:			SIZE A DWG. NO. P7 REV
FINISH NA				
DO NOT SCALE DRAWING				SCALE: 1:5 SHEET 12 OF 20

NEXT ASSY | USED ON

APPLICATION

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	HUMAN-POWERED MIXER
		DIMENSIONS ARE IN IN	DRAWN	NS	3/21/2017	TITLE:
		TOLERANCES: 1/8IN	CHECKED			3IN DRUM STOP (U-FRAME)
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL STEEL TUBE	COMMENTS:			SIZE A / DWG. NO. P8 / REV
NEXT ASSY	USED ON	FINISH NA				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:1 / SHEET 13 OF 20



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APPLICATION	

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DIMENSIONS ARE IN IN
TOLERANCES: 1/8IN

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
MILD STEEL BAR STOCK

FINISH
NA

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	CM	3/21/2017
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

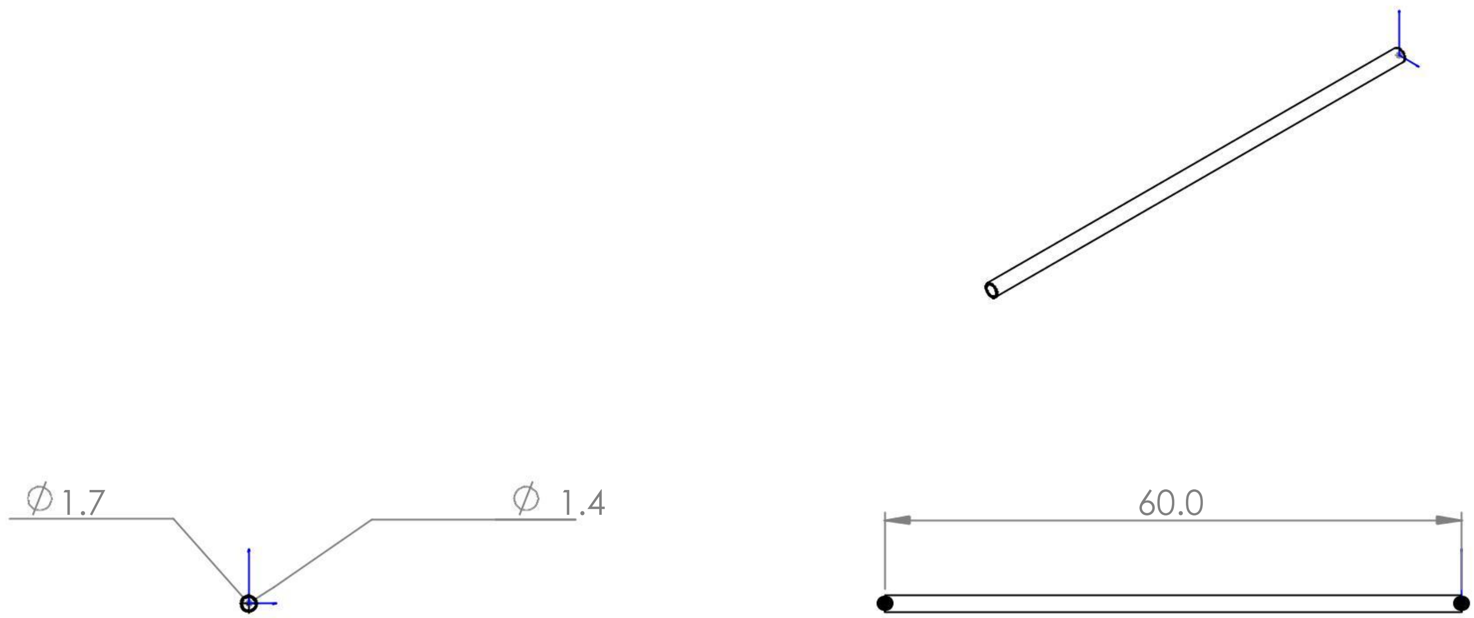
COMMENTS:

HUMAN-POWERED MIXER

TITLE:
Lever Arm

SIZE A | DWG. NO. P12 | REV

SCALE: 1:5 | SHEET 17 OF 20



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN IN

TOLERANCES: 1/8IN

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL STEEL TUBE

FINISH NA

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	NS	3/21/2017
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

HUMAN-POWERED MIXER

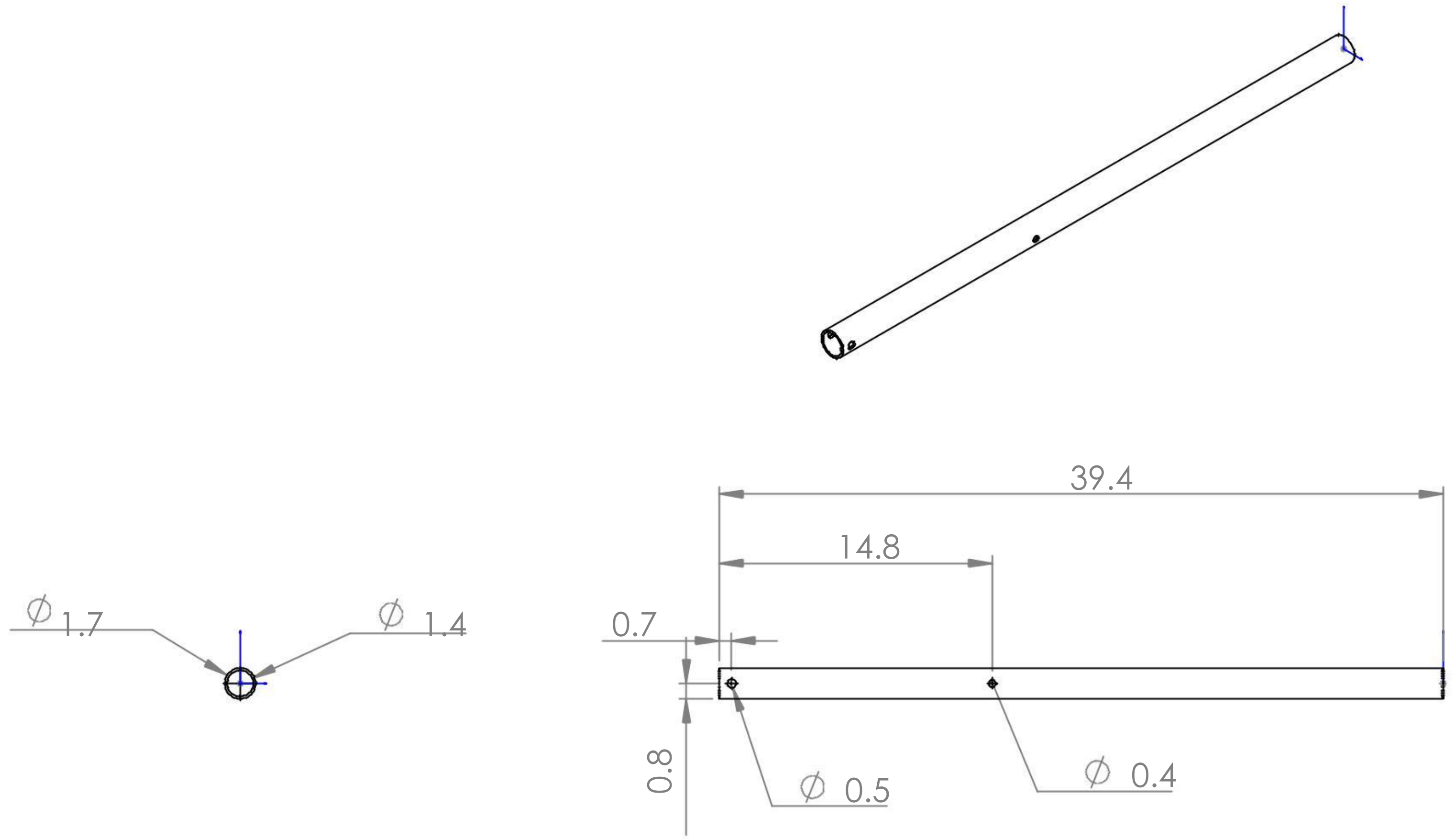
TITLE: 60in TUBE (BASE)

SIZE A DWG. NO. P1 REV

SCALE: 1:20 SHEET 6 OF 20

NEXT ASSY USED ON

APPLICATION



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APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN IN
TOLERANCES: 1/8IN

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
STEEL TUBE

FINISH
NA

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	NS	3/21/2017
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

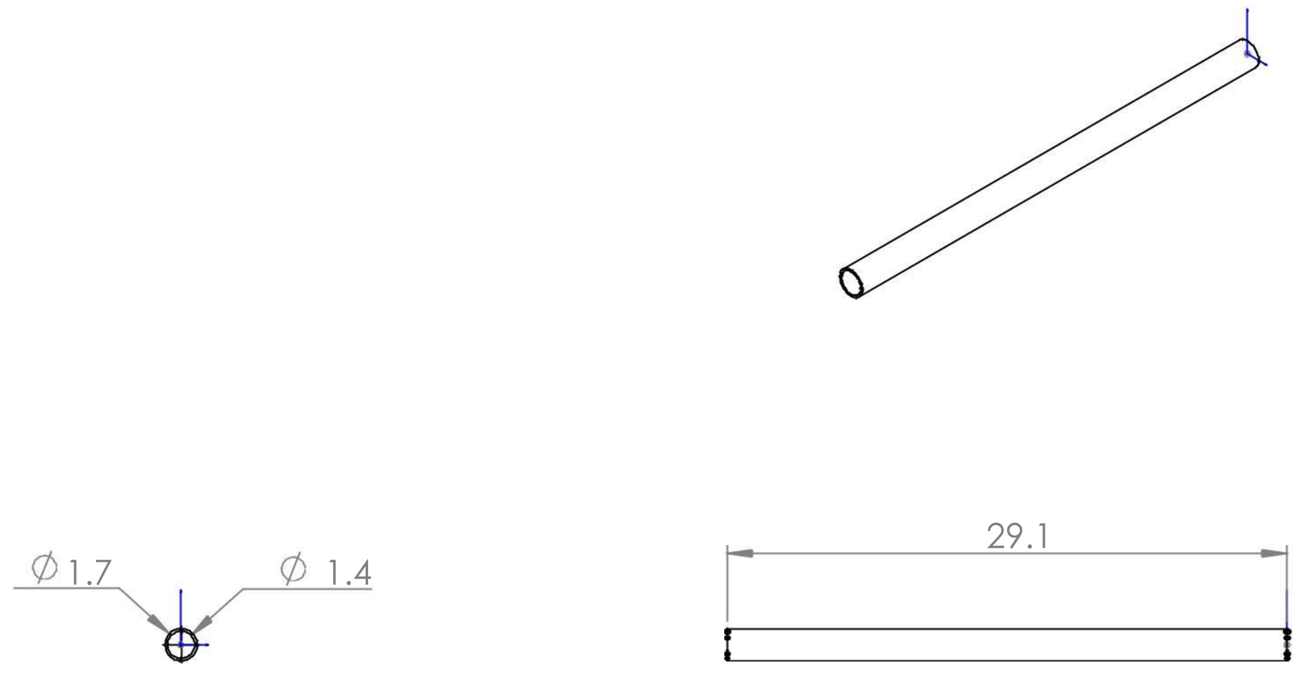
HUMAN-POWERED MIXER

TITLE:

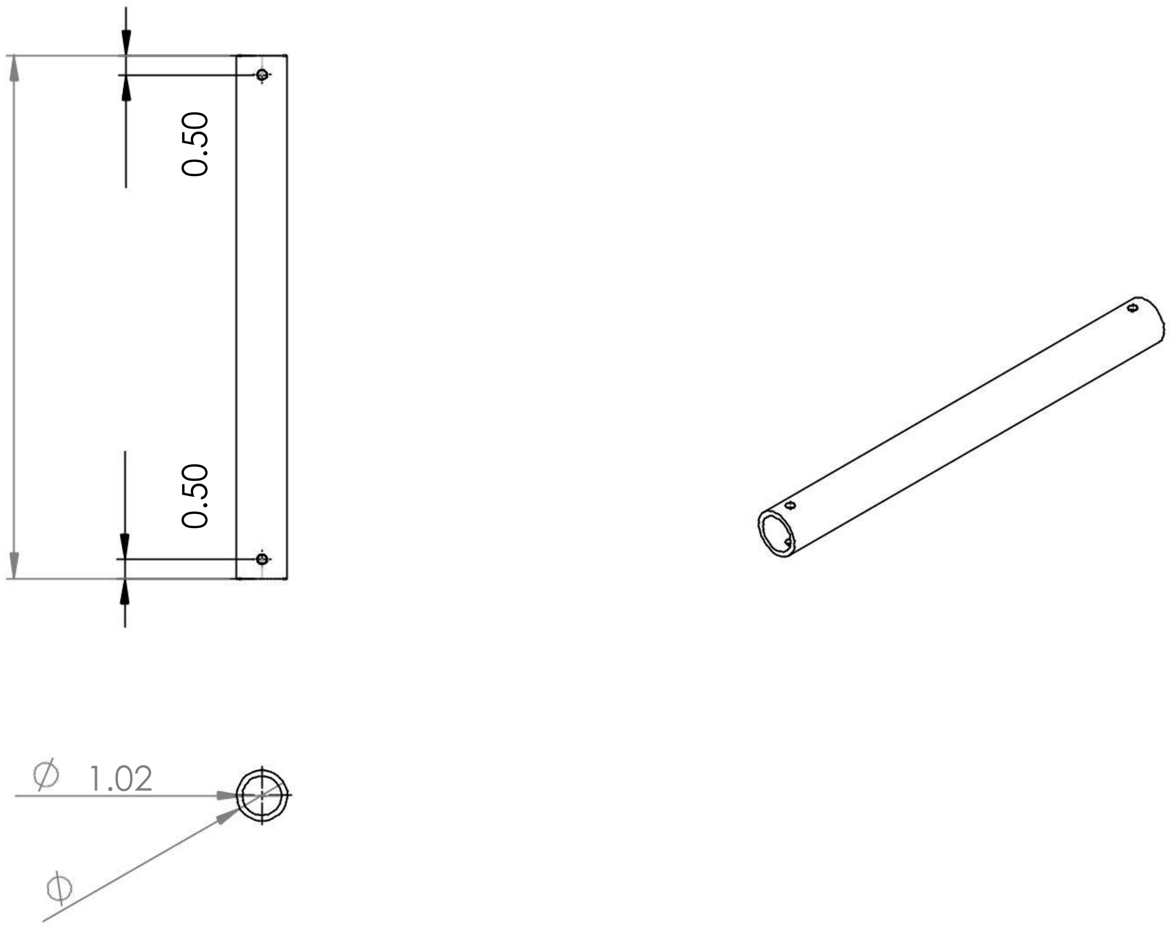
38in TUBE (BASE)

SIZE A | DWG. NO. P3 | REV

SCALE: 1:10 | SHEET 8 OF 20



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	HUMAN-POWERED MIXER
		DIMENSIONS ARE IN IN	DRAWN	NS	3/21/2017	TITLE:
		TOLERANCES: 1/8IN	CHECKED			29in TUBE (BASE)
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL STEEL TUBE	COMMENTS:			SIZE A DWG. NO. P2 REV
NEXT ASSY	USED ON	FINISH NA				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:10 SHEET 7 OF 20



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN IN

TOLERANCES: 1/8IN

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
SCHEDULE 40 PVC

FINISH
NA

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	CM	3/21/2017
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

HUMAN-POWERED MIXER

TITLE:

Rachet Cross-Member

SIZE A DWG. NO. P13 REV

SCALE: 1:5 SHEET 18 OF 20

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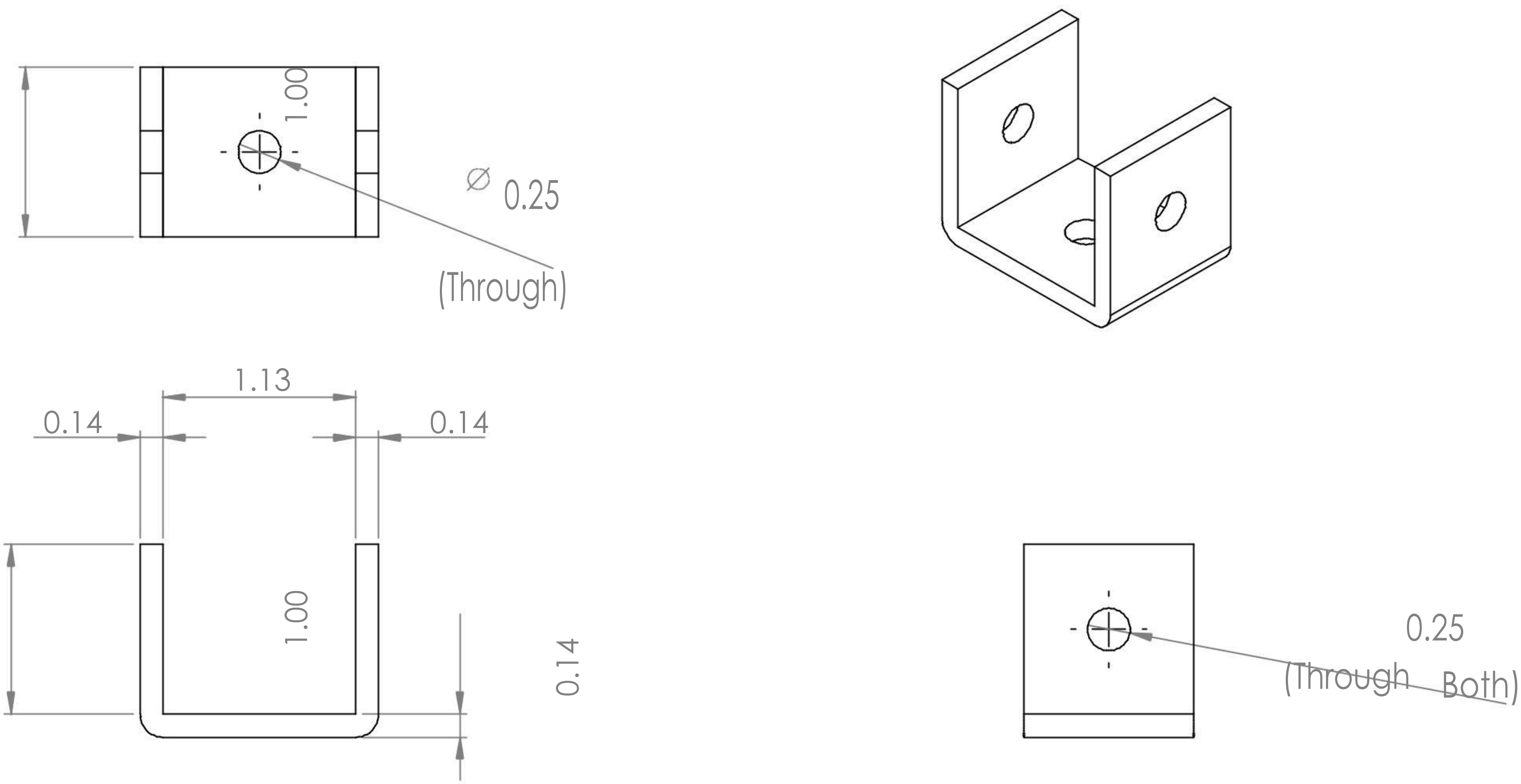
APPLICATION	



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN IN
TOLERANCES: 1/8IN
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
10 GAUGE STEEL SHEET METAL
FINISH
NA
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	CM	3/21/2017
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

HUMAN-POWERED MIXER

TITLE:

Bracket for Ratchet Handle

SIZE A | DWG. NO. P11 | REV

SCALE: 1:1 | SHEET 16 OF 20

Appendix G: Human-Powered Concrete Mixer Construction Manual

1. **Purpose**
    a. The purpose of this manual is to provide a detailed description of how to construct the Human-Powered Concrete Mixer (HPCM).
    b. This manual is **not** intended to give the user specifications for manufacture of individual parts.
    c. For details on manufacture and/or modification of parts, see Detail Drawings (Appendix F).
2. **Audience Assumptions**
    a. This manual is intended for individuals and/or groups that have purchased and/or obtained rights to the HPCM.
    b. The user of this construction manual has a basic working knowledge of the use of basic construction tools, such as:
        i. Allen Wrench
        ii. Open End Wrench
        iii. Electric, Hand-Held Power Drill
    c. The user is in good physical health and able to carry and move and carry loads of about 100 lbs.
    d. The user will be assisted by another person. DO NOT attempt construction without at least 2 people.
    e. For each placement of a connector, **loosely tighten** the set screw. Ensure that a final tightening of each set screw is done once the product is completed.
3. **Materials**
    a. For part details, see Detail Drawings (Appendix F).
    b. In order to construct the HPCM, the user must have the following materials:

Material	Part Number	Description	Quantity
Steel Tube	LF-001	Widthwise Tubing in Lower Frame	4
	LF-002	Lengthwise Tubing in Lower Frame	2
	LF- 003	Vertical Tubes in Lower Frame	2
	UF-001	Lengthwise Tubing of Upper Frame	2
	UF-002	Back Tubing of Upper Frame	1
	UF-003	Vertical Tubing of Lower U-Bars	4
	UF- 004	Widthwise Tubing of Lower U-Bars	2
	UF-005	Vertical Tubing of Upper U-Bar	2
	UF-006	Horizontal Tubing of Upper U-Bar	1
	UF-007	Drum Stops	2
	PT- 001	Connector Tubing to Upper Frame	2
Wood Pieces	UF-008	Lengthwise 2x4 for Lower U-Bars	2
	UF-009	Widthwise 2x4 for Upper U-Bar	1
	UF- 010	4x4 Drum Stops	2
Connectors	-----	Socket T	14
	-----	4-way Socket T	2
	-----	Elbow	10
Flat Iron	PT-002	Connection from Tubing to Axle	2
Angle Iron	PT-003	Chain Whip Handles	2
	D-002	Drum Paddles	4
Caster Wheels	-----	Upper Frame Drum Rollers	6
Bike Wheels	-----	Bike Rims with Tubes, Wheels, Freewheels, and Axles	2
Bike Chain	-----	Chain used in Chain Whip	2

½ inch bolts	-----	Connector Between Upper and Lower Frame	2
Steel Cable	-----	Stabilizing Cables for Lower Frame	15 ft
Cable Connectors	-----	Connectors for Steel Cables	8
Turnbuckle	-----	Used to connect Steel Cables	4
U bolts	-----	Used to Connect 2x4 to Tubing	6
Eye Bolts	-----	Used to Connect Steel Cable	3
1 inch ¼ in d screws	-----	-----	10
1.5 inch ¼ in d screw	-----	-----	10
Lock Washers	-----	-----	1
Rubber Gasket	-----	-----	12
Washers	-----	-----	10
¼ in nuts	-----	-----	20

4. Procedure

a. The following is an overview of the Procedure:

Section	**Part of Procedure**
4.1	Construction of Lower Frame
4.2	Construction of Power Transmission
4.3	Construction of Upper Frame
4.4	Construction of Drum
4.5	Connection of Integration of Subsystems

4.1 Construction of Lower Frame

1) Prepare pieces UF-002 and UF-003 by inserting Eye-bolts and connecting the cable using cable connectors and swaging tool.
2) Place 4-way socket T on UF-002, such that the connector is directly in the middle of piece.
3) Attach an elbow fitting to each end of UF-002 such that the ends of the elbow are facing the same direction.
4) Repeat for the other UF-002 piece, such that both appear as in **Figure F.1**:
5) Place the 3 UF-001 pieces in the elbow and socket-T fittings attached to the UF-002 pieces, such that they appear as in **Figure F.2**:

Figure F.2

6) Place through-T fittings on each vertical upright such that the edge of the fitting is 350 mm away from the end of bottom of the tube (the side that does NOT have a hole drilled for a ½ inch bolt.

7) Connect the two UF-003 pieces by inserting the final UF-001 piece between them and placing in the through-T fittings.

8) Insert UF-003 tubing into vertical openings of the socket-T fittings such that the holes for the ½ inch bolts are in line with each other.

9) Connect the cables, using the turnbuckle to ensure proper tension in the cables, such that the upper frame appears as in **Figure F.3:**

Figure F.3

4.2 Construction of Power Transmission

1) Attach freewheel to Bicycle Axle
2) Make Chain Whip
    a) Wrap Chain around Freewheel
    b) Connect with pins to pre-drilled holes in angle iron
    c) Repeat for second wheel
3) Connect Angle Iron Handles, as shown below:

4.3 Construction of Upper Frame

1) Construct the Lower U-Bars for the upper frame
    a) Place elbow connectors on both ends of the UF-004 pieces such that the other ends of the elbow or pointing in the same orientation
    b) Place UF-005 pieces into the elbow fittings
    c) Repeat for Second Lower U-Bar
2) Attach the Caster Wheels to the UF-008 pieces at locations specified in detail drawings
3) Attach the UF-008 2x4s to the Lower U-Bars such that they appear as in **Figure F.4.**

Figure F.4

4) Attach 3 through T-fittings and 2 elbow fittings to the UF-001 pieces such that they appear as in **Figure F.5 and F.6**

Figure F5

Figure F6

5) Attach the connected U-bars to through T-fittings.
6) Attach U-002 in elbow fittings at the back of the upper frame.
7) Attach Power Transmission to Upper Frame
    a) Insert PT-001(with PT-002 attached) into the through T-fittings at the back of the upper frame.
    b) Insert Bike wheels by placing axle through UF-001 and PT-002.
    c) Tighten nuts to fasten.
8) Finished Upper Frame when combined with Power Transmission should appear as follows:

4.4 Construction of Drum

1) Attach paddles to inside of drum using bolts and holes previously drilled.

4.5 Integration of Subsystems

1) Connect the Lower Frame and Upper Frame by inserting ½ inch bolt through the connecting holes.
2) Place Drum in Upper Frame such that it is resting on the Caster Wheels of the bottom u-frames and the bicycle wheels in the power transmission system.
3) Add Top U-bar for added stability.

5 User Manual

1) Mixing Concrete
    a) After ensuring safe surroundings, begin by pouring all dry materials into the drum
    b) Start powering the mixer by moving the handle up and down. The freewheels are attached in such a way that the drum will be powered when powering upwards and downwards.
    c) Slowly begin adding water until the desired consistency is achieved.
    d) Continue mixing for approximately 2 minutes.
    e) If any large clumps form in the mixer, use of a shovel is advised to break these up.
2) Pouring Concrete
    a) After the drum has come to a complete stop, insert the drum stops.
    b) Place desired receptacle inside the lower frame at the front of the drum
    c) Using the handles at the back of the mixer, tip the drum forward until all of the mix is out of the drum
    d) Ensure that drum stops are removed before mixing next batch.
3) Moving the Mixer
    a) Disassemble subassemblies, reversing the steps presented in 4.5.
    b) It is recommended that each part be carried by 2 individuals.

Appendix G: Senior Design Conference Slides


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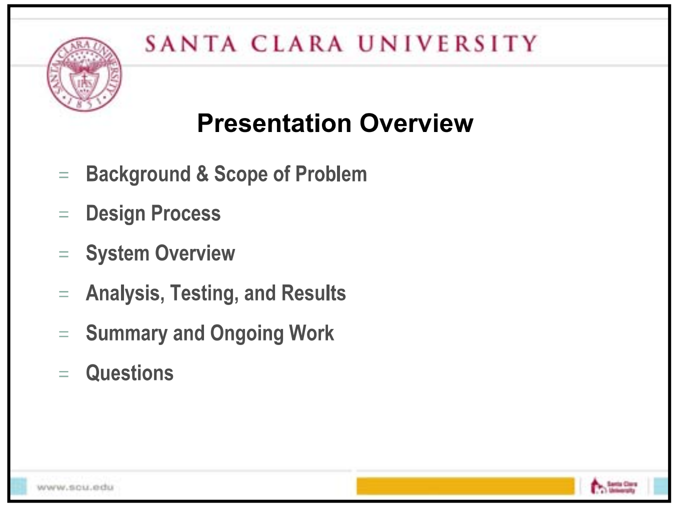
Human-Powered Concrete Mixer
Connor McLoughlin, Nathan Metzger,
Nick Szychowski, Madelyn Gustafson
XILINX
Amigos for Christ
Miller Center
www.scu.edu
SCHOOL OF ENGINEERING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Presentation Overview
Background & Scope of Problem
Design Process
System Overview
Analysis, Testing, and Results
Summary and Ongoing Work
Questions
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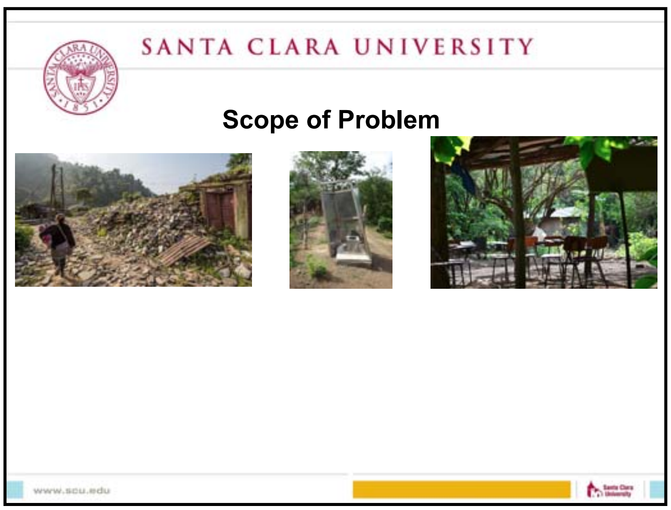
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Scope of Problem
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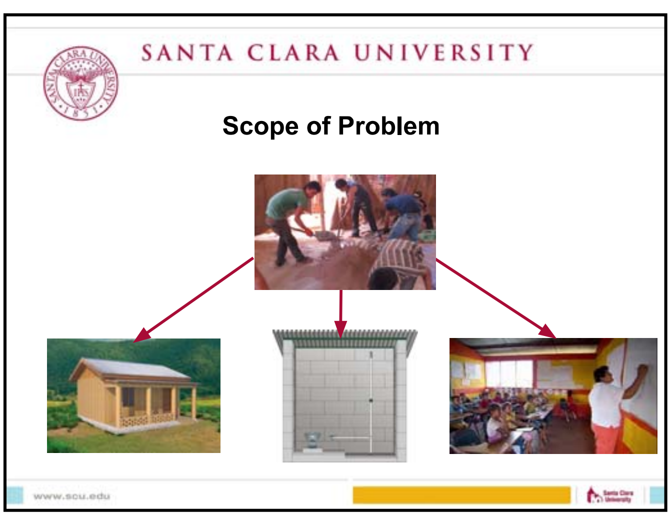
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Existing Solution
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Problems with Existing Solution

- Up-Front Cost ($500-$4000)
- Lack of Mobility
- Recurring Costs
- Sustainability

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Design Criteria

- Low Cost
- Efficient
- Mobile
- Reproducible

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Our Solution

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Initial Design - Specifications

Specification	Value	Relation to Existing Methods
Volume	0.08 m^3 (~21 gallons)	Matches hand-mixing volume
Rotational Speed	20 RPM	Matches gas-powered RPM
Mix Time	5 minutes	⅓ of hand-mixing time
Number of Operators	2 operators	⅓ of hand-mixing operators

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Presentation Overview

- Background and Scope of Problem
- **Design Process**
- System Overview
- Analysis, Testing, and Results
- Summary and Ongoing Work
- Questions

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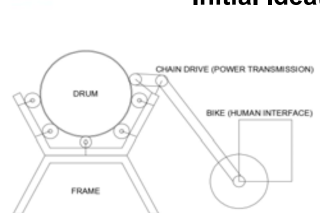
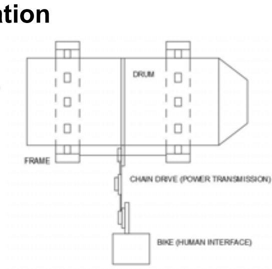
Initial Ideation



Side View



Top View

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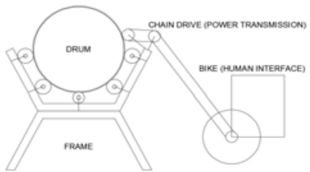
Problems Encountered

- No unloading mechanism
- No mixing at an angle
- Spilling without lid
- No visibility or access with lid



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Initial Design - Features

- Bicycle Powered
- Gear Train in power transmission
- Welded Connections

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Summary of Design Changes

Subsystem	Initial Design	Design Change	Reason for Change
Frame	Welded Connections	Fittings with Set Screws	Cost
	Square Tube	Cylindrical Tube	Cost, Manufacturability
Power Transmission	Gear Train	Ratcheting Handles with Freewheels	Cost, Manufacturability
	Chain Drive	Friction Drive	Cost, Manufacturability, Safety

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Design Changes - New Specifications

- Mixer to be used at auxiliary sites
- Size Requirements
- Mobility
- Modular Design

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Presentation Overview

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System Overview

Subsystem: Lower Frame

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Subsystem: Lower Frame

- Bears majority of load
- Stability and Safety
- Steel tube and fittings

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Subsystem: Upper Frame

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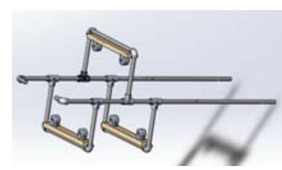
Subsystem: Upper Frame

- Maintain axis of rotation
- Stable interface between drum & bike wheels
- Joint allows drum to tip and pour out concrete



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Subsystem: Power Transmission

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Subsystem: Power Transmission

- Friction Drive
- Ratchet handle drives bike wheels
- Handle length provides mechanical advantage
- Bike wheels drive drum rotation

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Subsystem: Power Transmission

- Sprocket is a ratcheting free wheel
- Allows both wheels to be powered by handle
- Chain whip type connection

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Subsystem: Power Transmission

- Uses standard bike freewheels
- Ratcheting allows wheels to be powered alternately

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Subsystem: Drum

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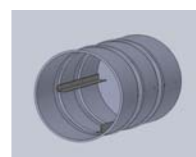
Subsystem: Drum

- 55-gallon oil drum
- Available everywhere
- Internal paddles



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Manufacturing Processes

- Materials
  - Hardware Store
  - Global Online Retailers
- Construction
  - Santa Clara Machine Shop

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Presentation Overview

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Bending Moment on the Bolt

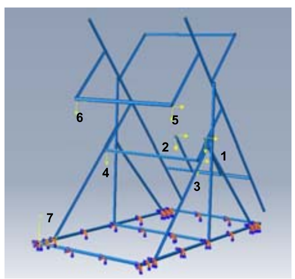
- Initial hand calculations done for feasibility
- 11,323 psi bending stress
  - Steel yield strength 36,000 psi
- Other calculations couldn't be done by hand

What is Finite Element Analysis

- Way to simulate a loaded system
- Provides resulting stresses and strains for varying loads
- Done using Abaqus Software

Load Placement

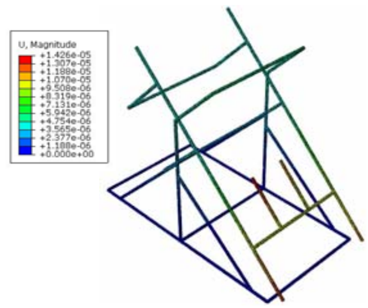
Node	Placement	Load (lb-f)
1	Left Wheel	125
2	Right Wheel	31.2
3	Left Middle	62
4	Right Middle	16
5	Left Front	5.4
6	Right Front	5.4
7	Low Bars	Fixed



Load Analysis Results

- Displacement (in Meters) results at normal loading
- Maximum displacement occurs at wheel axle support
- Maximum displacement is 14 μm

  (hair width)



Vibration Analysis

- Found Natural Frequencies
  - When the mixer would be at resonance and failure occurs
- Drum would need to rotate at 586 RPM at lowest

Mode	Natural Frequency (Hz)
1	28.4
2	31.3
3	31.3
4	40.5
5	51.4

Cost Analysis

Mixer	Cost
High-End Gas-Powered	$4000
Lower-End Gas-Powered	$500
Initial HPCM Design	$1600
Final HPCM Design	$544

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Mobility Testing

	Weight(lbs)	
	HPCM	*Portable Gas-Powered*
Lower Frame	59.6	----
Upper Frame	94.3	----
Drum	52.2	----
Total	**206.1**	**180-800**

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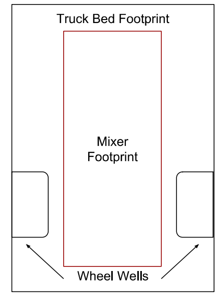
Mobility Testing

- Spec from Amigos for Christ was 3.5ft x 7ft
- Modules are 3ft x 6.5ft
- Each module can be moved by 1-2 people



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Test Results: Drum Speed

Test	Drum Speed (RPM)
Empty Drum	12.25
40 lb Concrete	9.75
80 lb Concrete	10.25
120 lb Concrete	13.5
160 lb Concrete	14.25

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Demonstration of Operation

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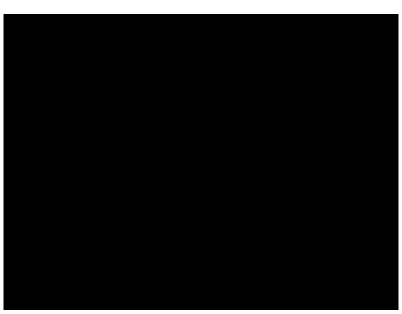
Unloading Demonstration



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Mix Product

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Presentation Overview

- Background and Scope of Problem
- System Overview
- Design Process
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- Questions

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Project Results Overview

Criteria	Relevant Aspects of Design	Potential Improvements
Low Cost	- Total Cost: $544 - No recurring costs from gas	Less Fittings, Cheaper Materials
Efficient	- Mix Time: 5 min - Batch Size: 21 gallons	More ergonomic design
Mobile	- Modular Design: 3 modules - Weight: 210 lbs in 3 modules	Lighter-weight materials
Reproducible	- Accessible Parts - Reproducible manufacturing	Documentation

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Next Steps

- Concrete Strength Tests
- Documentation for Amigos for Christ
- Blade Geometry Tests
- Increase coefficient of friction between drum and wheels

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Lessons Learned

- Importance of design iterations
- Ethical decision making
- Communication with non-profits
- Challenge of designing for remote/rural developing communities

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Summary

- Low Cost
- Efficient
- Reproducible
- Mobile
- Innovative

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Presentation Overview

- Background and Scope of Problem
- System Overview
- Design Process
- Analysis, Testing, and Results
- Ongoing Work
- Questions

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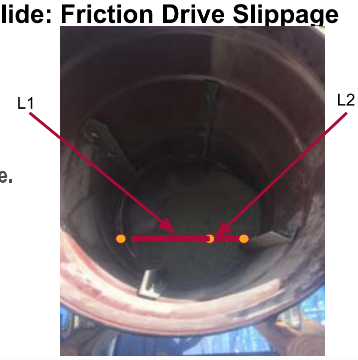
Additional Slides

1. Friction Drive Slippage
2. Scope of Work
3. Power Calculation
4. Detailed Budget
5. Freewheel Schematic

Additional Slide: Friction Drive Slippage

- Uneven distribution
- Left wheel has less moment arm, must provide greater torque.

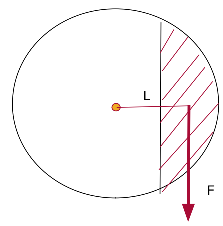


Additional Slide: Scope of Use

- 2.8 ft^3 per batch
- Modern Bathroom: 36-40 ft^3 for foundation
- 13-14 batches
- 30 minutes + labor saved
- Schools vary, but much larger foundations

Additional Slide: Power Calculation

- Worst-case loading scenario
- Equation: $\tau = F*L$; $P = \tau*\omega$
- Assumptions
  - 72 kg (160lb = 0.08m^3)
  - 15 rpm
- Power Required = 88 Watts



Free Body Diagram

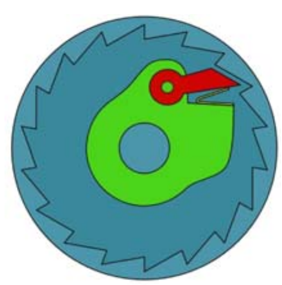
Additional Slide: Detailed Budget

Part	Per Unit Cost ($)	# of Units	Total
Socket T	$2.30	14	$32.20
4 way socket T	$5.40	2	$10.80
Elbow	$6.00	10	$60.00
Refurbished Dr	$65.00	1	$65.00
4x4	$11.00	0.1	$1.00
2x4	$2.50	1	$2.50
Steel tube	$20.00	5.5	$110.00
Angle iron	$16.00	1.4	$22.40
Bar stock	$5.80	0.5	$2.90
Caster wheels	$7.00	6	$42.00
Bike wheel rim:	$25.00	2	$50.00
Bike tubes	$9.00	2	$18.00
Axles	$9.00	2	$18.00
Free wheels	$12.00	2	$24.00
Bike chain	$15.00	0.25	$3.75
1/2in bolts	$1.50	2	$3.00
Cable	$0.35	8	$2.80
Cable Connecti	$1.50	8	$12.00
Turnbuckle	$7.00	4	$28.00

Part	Per Unit Cost $	# of Units	Total
Ubolts	$1.50	6	$9.00
Caster screws	$2.00	2	$4.00
Eye bolts	$1.50	3	$4.50
1 in ¼ in screws	$0.40	10	$4.00
1.5 in ¼ in screws	$0.50	10	$5.00
Lock washers	$2.00	1	$2.00
Rubber Gasket	$3.00	1	$3.00
Washers	$1.00	1	$1.00
Wing nuts	$2.00	2	$2.00
1/4in nuts	$5.00	1	$5.00

Total:			$544.00

Additional Slide: Freewheel Schematic



Appendix H: Detailed Budget

Part	Per Unit Cost ($)	# of Units	Total
Primary Materials			
Socket T	$2.30	14	$32.20
4 way socket T	$5.40	2	$10.80
Elbow	$6.00	10	$60.00
Refurbished Drum	$65.00	1	$65.00
4x4	$11.00	0.1	$1.00
2x4	$2.50	1	$2.50
Steel tube	$20.00	5.5	$110.00
Angle iron	$16.00	1.4	$22.40
Bar stock	$5.80	0.5	$2.90
Caster wheels	$7.00	6	$42.00
Bike wheel rims	$25.00	2	$50.00
Bike tubes	$9.00	2	$18.00
Axles	$9.00	2	$18.00
Free wheels	$12.00	2	$24.00
Bike chain	$15.00	0.25	$3.75
1/2in bolts	$1.50	2	$3.00
Cable	$0.35	8	$2.80
Cable Connections	$1.50	8	$12.00
Turnbuckle	$7.00	4	$28.00
Hardware			
Ubolts	$1.50	6	$9.00
Caster screws	$2.00	2	$4.00
Eye bolts	$1.50	3	$4.50
1 in ¼ in screws	$0.40	10	$4.00
1.5 in ¼ in screws	$0.50	10	$5.00
Lock washers	$2.00	1	$2.00
Rubber Gasket	$3.00	1	$3.00
1/4in nuts	$5.00	1	$5.00
Total:			**$544.00**

Appendix I: Selection Matrices

Table D.1. Selection Matrix for Drum

	TARGET or	DESIGN IDEAS									
CRITERIA	FACTOR	1 = Baseline		55 Gallon Oil Drum		Keg		Custom Made		Bucket	
Time – Design	3	3		2		2		5		3	
Time – Build	3	3		2		1		4		3	
Time – Test	3	3		4		3		5		1	
Time Score	10		10		8.89		6.67		15.56		7.78
Cost – Prototype	5	$ 5.00		$ 100.00		$ 20.00		$ 500.00		$ 2.00	
Cost – Production	5	$ 5.00		$ 30.00		$ 12.00		$ 750.00		$ 0.50	
Cost Score	5		5		65.00		16.00		625.00		1.25
Weight	4	3	12	2	8	4	16	4	16	2	8
Opening Shape	1	3	3	2	2	5	5	5	5	2	2
Drum Diameter	3	3	9	2	6	1	3	4	12	1	3
Hole Diameter	2	3	6	4	8	1	2	4	8	1	2
Material	4	3	12	5	20	5	20	5	20	1	4
Acquirability	5	3	15	5	25	1	5	1	5	5	25
Ease of Manipulation	2	3	6	3	6	3	6	5	10	2	4
	TOTAL		63.0		16.1		49.3		-549.6		54.0
	RANK										
	% MAX		100.0%		25.6%		78.3%		-872.3%		85.7%
	MAX	63.0									

Table D.2. Selection Matrix for Frame

	TARGET or	DESIGN IDEAS											
CRITERIA	FACTOR	1 = Baseline		Bike in Separate		Bike in Integrated		Horizontal		Angled Rotation		Integrated Power	
Time – Design	3	3		1		4		5		5		2	
Time – Build	3	3		2		3		3		5		3	
Time – Test	3	2		2		3		3		5		4	
Time Score	10		8.88889		5.56		11.11		12.22		16.67		10.00
Cost – Prototype	10	$ 10.00		$100		$ 100.00		$ 300.00		$ 250.00		$ 70.00	
Cost – Production	10	$ 10.00		$ 100.00		$ 100.00		$ 250.00		$ 300.00		$ 20.00	
Cost Score	1		1		10.00		10.00		27.50		27.50		4.50
Weight	1	3	3	4	4	2	2	1	1	1	1	5	5
Materials	2	3	6	5	10	4	8	2	4	2	4	4	8
Design Complexity	3	3	9	2	6	2	6	4	12	2	6	1	3
Ease of Tilt	5	3	15	4	20	4	20	2	10	5	25	1	5
Tilt Degrees	3	3	9	4	12	4	12	1	3	5	15	1	3
Parts Required	3	3	9	2	6	3	9	5	15	2	6	5	15
Safety Issues	5	3	15	3	15	4	20	5	25	4	20	2	10
Stability	5	3	15	3	15	3	15	5	25	3	15	2	10
	TOTAL		81.0		82.3		80.8		65.2		57.7		54.4
	RANK												
	% MAX		98.4%		100.0%		98.1%		79.1%		70.1%		66.1%
	MAX	82.3											

Table D.3. Selection Matrix for Power Transmission

	TARGET or	DESIGN IDEAS													
CRITERIA	FACTOR	Manually Turning		Gears		Chain Drive		Belt Drive		Friction Drive		Rope		Roller Chain	
Time – Design	1	1		5		5		3		2		2		5	
Time – Build	1	1		3		3		3		1		1		3	
Time – Test	1	1		4		4		4		5		4		5	
Time Score	11		11		44.00		44.00		36.67		29.33		25.67		47.67
Cost – Prototype	1	$ 1.00		$ 200.00		$ 120.00		$ 100.00		$ 200.00		$ 40.00		$ 200.00	
Cost – Production	1	$ 1.00		$ 165.00		$ 60.00		$ 50.00		$ 150.00		$ 20.00		$ 175.00	
Cost Score	1		1		182.50		90.00		75.00		175.00		30.00		187.50
Weight	2	3	6	2	4	3	6	3	6	4	8	4	8	4	8
Speed	4	3	12	5	20	5	20	5	20	5	20	4	16	5	20
Acquirability	5	3	15	3	15	4	20	4	20	5	25	5	25	2	10
RPM	3	3	9	5	15	5	15	5	15	3	9	3	9	4	12
Upkeep	4	3	12	4	16	3	12	3	12	1	4	2	8	3	12
Flexibility	4	3	12	4	16	2	8	4	16	5	20	3	12	2	8
	TOTAL		66.0		-128.5		-41.0		-10.7		-106.3		34.3		-153.2
	RANK														
	% MAX		100.0%		-194.7%		-62.1%		-16.2%		-161.1%		52.0%		-232.1%
	MAX	66.0													

Table D.4. Selection Matrix for Human Interface

	TARGET or	DESIGN IDEAS																			
CRITERIA	FACTOR	1 = Baseline		Bike Pedaling		Rope		Foot Pedal		Rowing		Bike Pump Motion		Solar Pannel		Wind Turbine		Stirring		Treadmill	
Time – Design	3	3		2		1		3		1		1		2		1		1		2	
Time – Build	3	3		3		0.5		2		2		1		2		1		1		2	
Time – Test	3	3		4		0.5		2		3		2		3		3		1		1	
Time Score	10		10		10.00		2.22		7.78		6.67		4.44		7.78		5.56		3.33		5.56
Cost – Prototype	60	$ 60.00		$ 150.00		$ 10.00		$ 35.00		$ 500.00		$ 20.00		$ 500.00		$ 500.00		$ 10.00		$ 500.00	
Cost – Production	90	$ 90.00		$ 30.00		$ 40.00		$ 45.00		$ 30.00		$ 15.00		$ 30.00		$ 30.00		$ 5.00		$ 120.00	
Cost Score	10		10		14.17		3.06		5.42		43.33		2.50		43.33		43.33		1.11		48.33
Rotational Speed	4	3	12	4	16	1	4	3	12	2	8	2	8	2	8	2	8	1	4	2	8
Amount of Mixed Mat'l	3	3	9	3	9	2	6	3	9	2	6	3	9	3	9	3	9	2	6	3	9
Volume of Drum	2	3	6	3	6	2	4	3	6	1	2	3	6	3	6	3	6	1	2	3	6
Weight	2	3	6	3	6	2	4	3	6	1	2	3	6	3	6	3	6	1	2	3	6
Necessary Power	5	3	15	5	25	2	10	4	20	3	15	2	10	2	10	2	10	2	10	3	15
Output Torque	5	3	15	5	25	2	10	4	20	3	15	2	10	2	10	2	10	1	5	3	15
Cost	1	3	3	3	3	5	5	3	3	1	1	4	4	1	1	1	1	5	5	1	1
Price	1	3	3	4	4	5	5	3	3	1	1	4	4	1	1	1	1	5	5	1	1
	TOTAL		69.0		89.8		62.7		85.8		20.0		70.1		19.9		22.1		54.6		27.1
	RANK																				
	% MAX		76.8%		100.0%		69.8%		95.5%		22.3%		78.0%		22.1%		24.6%		60.7%		30.2%
	MAX	89.8																			

Appendix J: Mixing Test Data

Test	Drum Speed (RPM)
Empty Drum	12.25
40 lb Concrete	9.75
80 lb Concrete	10.25
120 lb Concrete	13.5
160 lb Concrete	14.25